Governmental Policies to Promote Biogas Production, Boosting Role of Biogas in Economic Growth of Developing Nations

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Abstract Anaerobic digestion (AD) is a renewable process more studied around the world. This process allows the use of agro-industrial waste, such as manure, sewage water, sorghum, corn, and cane waste, among others, to be converted into heat and electrical energy. AD has seen as an alternative form for being a sustainable bioenergy practice, aiming health, pollution, energy, and sanitation concerns. In developed countries, the biogas system has focused on large-scale biogas plants, based on farms, electricity, and heat in commercial and industrial form. On the other hand, in developing countries, the biogas is used for cooking and lighting, which is produced in small or domestic-scale digesters. However, in these last countries, the government has not bet on the implementation of biogas systems, thus generating a series of challenges for the implementation of these systems, being the main challenges due to technical deficiency, lack of adequate infrastructure, low economic budget, and low support from the government. However, high levels of global pollution and the development of new techniques have been attributed to consider implementing these systems around the world. Looking forward to this, positive prospects for pollution reduction, waste utilization, energy recovery, and economic gains for developed and developing countries will be discuss throughout this chapter based on the current governmental policies that enhances the economic growth to seek biogas production.

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1 Introduction

The concern to mitigate the environmental impact of fossil fuels with the interest in the reduction of greenhouse gases (GHG) emissions and several strategies have been developed in various areas. One of them is the generation of clean energy from a range of technologies. Anaerobic digestion (AD) is an alternative that involves the production of biogas, which has taken great interest for decades, being a highly competitive and studied process. After the energy crisis in 1970, anaerobic digestion underwent rapid development (Vasco-Correa et al. 2018). The generation of energy from biogas increased by 85% in the last two decades.

Countries in Europe and Asia, as well as the United States, have adopted the AD as an environmental mitigation method governed by policies and regulations, which allow the implementation of biogas production for energy generation. These countries are leaders in biogas production policies, and other countries from developing countries have joined this strategy, adopting policies of developed countries in the field, as well as creating their own policies.

A particular case is the European Parliament who promoted policies for energy production, thus estimating biogas production increased to 20,000 m^3 by 2030 (Lara Grando et al. 2017). Other investment programs promoting regulations in energy production, in the case of China and Germany, estimated a generation for 2020 of 6 GW_{ton} and a projection of 25 GW_{tot} for 2050, the case of India, its policies promoted the transformation of biomass into energy, with the creation of approximately 5000 biogas plants by the Ministry of New and Renewable Energy (MNRE). Other countries in Latin America and Africa are still developing strategies to mitigate climate change through AD. The Mexican government estimates that in 2050 greenhouse gas emissions will decrease approximately 50% with the implementation of biogas systems, and 4.8% of the energy will be produced from renewable sources.

However, AD systems still present great challenges for both developed and policy developing countries; therefore, in recent years, various strategies have been proposed for greater control of the AD process in biodigesters. In this chapter, some of the regulations and policies of example countries that carry out the strategies for the production of biogas and the reduction of greenhouse gases, as well as some limitations of the process and perspectives, are disclosed.

2 Brief History of Anaerobic Digestion Technology and Biogas

Anaerobic digestion was developed as a wastewater treatment process in configuration with a septic tank. This design was known as “Mouras’ Automatic Scavenger” and later was improved by Donald Cameron in 1895, in Exeter, England. Because of its success, the government of Exeter approved the treatment of the entire city’s wastewater by these septic tanks. Recognizing the value of the methane gas as value-added product was collected and used for heating and lighting (Rittmann and McCarty 2001).

The application of anaerobic digestion for biogas production gained popularity in 1900, but decreased after the 1950s, because of the low fossil fuels prices. Then after the energy crisis in the 1970, the biogas digestion experienced a rapid development (Vasco-Correa et al. 2018), for being a sustainable bioenergy practice, aiming health, pollution, energy, and sanitation concerns (Yousuf et al. 2016). In developing countries, the biogas is used for cooking and lighting, which is produced in small or domestic-scale digesters. Meanwhile in developed countries, digesters are larger, and farm based, where the biogas produced is used for electricity generation and heat biogas plants (Scarlat et al. 2018).

2.1 Asia

In 1988 China had 4.7 million household biogas plants; meanwhile by the late 1990s, India had over three million family-sized biogas plants. In 2007, China reached about 26.5 million biogas plants and India nearly four million family-sized biogas plants (Bond and Templeton 2011). Of late, an estimated of 100,000 modern biogas plants and 43 million residential-scale digesters were viable in China by 2014, generating about 15 billion m^3 of biogas (Scarlat et al. 2018). In recent years, Asia generated 4268 GWh, which represents only 4% of the energy produced in the world from biogas (IEA 2019).

2.2 European Union

France in the mid-1990 had over 1000 anaerobic digestion plants (Abbasi et al. 2012). Germany one of the European leaders in biogas production had 850 on-farm anaerobic digester plants with 500 m^3 of capacity in 2000 (Weiland 2010). The electrical capacity in Europe by 2013 was 7852 MW with 282 biomethane plants. Europe in that year had the greatest biogas production with 282 plants, estimating 9.4 TWh of biomethane. Most plants in the European Union are located in Germany (154 plants), Sweden (54 plants), and the Netherlands (23 plants) (REN21 2015). Germany is one of the leaders in energy, involving the biogas generation, had 10,971 large-scale biogas plants (WBA 2019).

2.3 Africa

In 2016, Africa accounted for 68,000 household biogas digesters installed by African Biogas Partnership Program, with an energy biogas capacity of 1494 MW. Kenya and Ethiopia had growing on biogas plants between 2014 and 2016, being in the more important countries in installation of new plants (Dubois et al. 2019). By 2017, it improved their production in 80% in 10 years (IEA 2019).

2.4 Central and Latin America

In 2007, Mexico, Cuba, and Colombia had 1050, 79, and 60 household plants, respectively. In 2009 Central America had a biogas energy capacity of 4 MW, producing 1GWh, but by the end of 2017, it had a capacity of 36 MW and a generation of 112 GWh from biogas (IEA 2019) (Table 1). Brazil had and average production of biogas of 582.7 m^3/day with a total 121,453 kW in 2019 (Freitas et al. 2019). The USA had over 1528 anaerobic digester plants and Canada more than 100 biogas systems in the same year (Viancelli et al. 2019).

Table 1 Global installed capacity of energy from bioenergy/biogas (MW)

Area	Technology	2011	2012	2013	2014	2015	2016	2017
Africa	Bioenergy	1104	1196	1290	1444	1485	1495	1501
	Biogas	9	10	11	11	23	29	34
Asia	Bioenergy	15,290	16,325	18,641	21,303	24,217	29,743	33,780
	Biogas	408	509	650	846	955	1097	1287
C America + Carib	Bioenergy	1482	1580	1657	1801	2098	2440	2495
	Biogas	11	11	15	14	23	32	36
Europe	Bioenergy	29,302	30,693	31,706	33,211	34,643	35,739	36,662
	Biogas	8474	9661	10,145	10,738	11,218	11,667	12,073
Middle East	Bioenergy	65	67	72	80	91	98	98
	Biogas	32	34	39	47	58	65	65
N America	Bioenergy	12,511	13,279	14,312	15,030	16,109	16,247	17,194
	Biogas	1946	2257	2425	2547	2524	2574	2724
Oceania	Bioenergy	1004	1009	1001	1012	1013	1009	1020
	Biogas	272	277	269	279	280	276	275
S America	Bioenergy	10,936	12,228	14,605	15,108	15,767	16,590	17,031
	Biogas	184	221	222	243	273	537	349

Source: IRENA (2019), Renewable Energy Statistics 2019, The International Renewable Energy Agency, Abu Dhabi

2.5 Global Generation

In 2000 the global energy production from biogas was about 13,184 GWh (Fig. 1) and with 2455 MW energy capacity (Table 1). Germany the leader in the European Union produces 38.5% of the biogas produced in the world and 6% of the bioenergy produced from only biogas in the world. The top five countries in production in 2017 were Germany, the USA, the UK, Italy, and China (IEA 2019). In general, the world generation of power from biogas improved 85% from 2000 to 2017. The USA, for example, produced 13,723 GWh in 2017, by 2005 it produced 6449 GWh of electricity. Another example is Italy that produced by 2000 only 567 GWh but by 2017 improved their production to 8299 GWh. The total production in 2017 was 87,932 GWh of electricity generation from biogas, showing the importance of this technology for energy production.

3 Mitigation Strategies for Climate Change

Climate change mitigation along with the reduction GHG emissions has evolved as a major challenge that worldwide society is facing nowadays (Ramanathan and Feng 2008). This is mainly due by the excessive amounts of anthropogenic emissions, where GHG-intensive from the energy and industry sectors are the largest contributors (Cadez and Czerny 2016). Hence, rapid actions to climate change mitigation and the urgent reduction of GHG are being done.

As mentioned before, biomass has emerged as an important source of carbon, mainly for systems that aim to meet strict climate targets. This energy source has been used for heat and electricity production, as transport fuel and a feedstock for

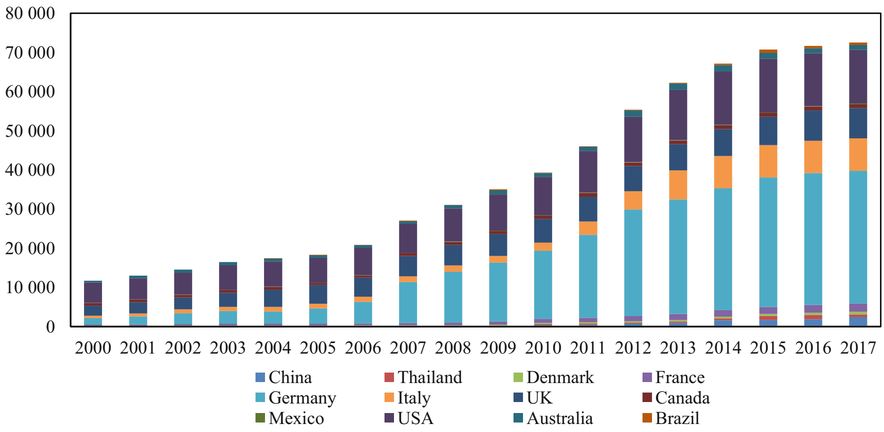

Fig. 1 Electricity generation from 2000 to 2017 (GWh). Source: IRENA (2019), Renewable Energy Statistics 2019, The International Renewable Energy Agency, Abu Dhabi

chemical compounds. From a policy perspective, the use of bioenergy has been widely implemented in big cities to reduce greenhouse gas GHG emissions and to improve energy security. However, in 2018 global energy-related CO_2 emissions rise 1.7% to a historic high of 33.1 Gt CO_2. Fossil fuels emissions accounted for 18.6 Gt CO_2 of emission growth, while coal use as power alone emissions exceeded to 10.1 Gt CO_2 for the first time, mostly in Asia. While China, India, and the accounted for 85% of the net increase in emissions (IEA 2019).

The most viable strategies to reduce GHG emissions depend on the nature of the gases itself in a particular firm. For example, firms with combustions emissions, which result from burning fossil fuels, implement rules to reduce fossil fuel consumption. Hence, strategies via GHG reduction depend on a specific characteristic of industrial processes.

Generally, four main options are taken for GHG-intensive firms to reduce climate change, which involved GHG restriction. The first one involves replacing conventional carbon-based materials (e.g., plastic) with eco-friendly (e.g., biodegradable), or recycled materials (e.g., recycled aluminum) (Boiral 2006; Jeswani et al. 2008). The second choice involves the replacement of carbon-based products by noncarbon-based products (e.g., steel products are replaced by wood products). The third alternative involves the usage of low carbon technologies (e.g., generating energy from renewable resources) (Jeswani et al. 2008; Kolk and Pinkse 2005). The fourth option is related to changes and improvements in industrial processed (e.g., utilization of inert electrodes for aluminum manufacture) (Cadez and Czerny 2016).

Globally, the United Nations Framework Convention on Climate Change (UNFCCC) was opened since 1992 where 154 nations signed the treaty in order to accomplish the main objective to "stabilize GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with earth's climate system" (UNFCCC 1992). Parties to the UNFCCC have met at conferences to discuss treaty goals which leads to Kyoto Protocol and Paris Agreement, among others, which have been signed in order to discuss, set, and adequate some objectives in order to stabilize GHG emissions in developed and developing countries.

The Kyoto Protocol was adopted in Kyoto, Japan, on December1997 and entered in force on February 2005, and currently, 192 parties are within the protocol. The Kyoto Protocol implemented the objective to reduce the onset of global warming by reducing GHG concentrations which applies to the six GHG listed as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HCFs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). This protocol has the same objective but with specific responsibilities since it acknowledges that the countries have different capabilities to mitigate the climate change due its economic development. Hence, developed countries have the obligation to reduce its current emissions based on the fact that they are historically responsible for the current levels of GHG in the atmosphere (UNFCCC 1998). Although the Protocol's first (2008–2012) and second (2012–2020) commitments set goals for emission reductions, the global emissions have increased dramatically, as mentioned earlier. Thus, negotiations were taken, after the second commitment period ends in 2020 in the framework of the UNFCCC Climate Change Conferences, which resulted in the adoption of the Paris Agreement.

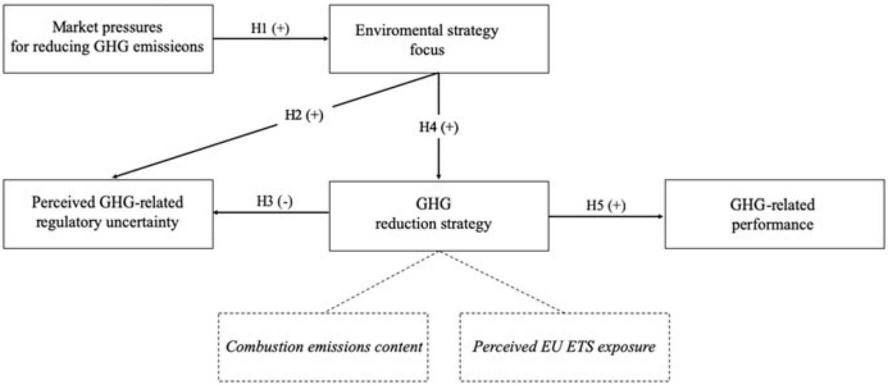

Fig. 2 Conceptual model of carbon reduction strategy (Scheme taken from Cadez et al. 2018). EU ETS: the European Union Emissions Trading Scheme

The Paris Agreement was negotiated in Le Bourget, France, on December 2015. Currently, it has been signed by 189 parties, with the exception of Iran and Turkey. The Paris Agreement long-term goal is to maintain the increase of global temperature to well below 2 °C above pre-industrial levels, to limit the increase to 1.5 °C and to increase the ability of parties to adapt to the adverse impacts of climate change. This last one in order to make "finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development." Also, this agreement also states that to reduce emissions is necessary to "achieve a balance achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases." According to the main long terms under the Paris Agreement, each country has to develop plans and report the contribution, if it has been made, to mitigate the global warming. However, it was not set a specific emission target by a specific date.

European schemes aim to increase the understanding of the climate change mitigation strategies of GHG-intensive firms, particularly their antecedents and effects. Some authors have proposed a conceptual model (Fig. 2), which includes three antecedents that affect directly or indirectly which affect GHG reduction strategies, two exogenous (market pressure and perceived GHG-related regulatory uncertainty) and one endogenous (environmental strategy focus).

This model also includes variables, the combustion emissions content, and the perceived European Union Emissions Trading Scheme (EU ETS) exposure. This model also includes variables as the combustion emissions content, and the perceived European Union Emissions Trading Scheme (EU ETS) exposure. The first variable (combustion emissions content) involves the ratio of combustion and process emissions in the total GHG emissions mix. While, the second variable (perceived EU ETS exposure) is an specific type of environmental exposure that will probably affect GHG reduction strategies. Which in matter of exposure, diverse structural characteristics are involved as the GHG-based materials (large emitters are more exposed than small emitters) (Damert and Baumgartner 2017). As mentioned earlier, the nature of emission in a particular firm is crucial to reach GHG reduction strategies of a firm (Cadez and Czerny 2010, 2016), while in the European Union Emissions Trading Scheme, the GHG-intensive firms are disproportionally exposed to regulatory requirements even if they are operating within the same regulatory framework (Hoffmann and Busch 2008).

This model led to find out that market pressures for reducing GHG emissions, perceived GHG-related regulatory uncertainty, and environmental strategy focus are important determinants of corporate GHG reduction strategies. However, the results varied depending on the type of emissions.

4 Public Policies of Developed Countries for the Implementation of Biogas Systems

The bioenergy production has gained in most of the developing countries a bio-based economy. Biogas technology is a way to contribute on a green low carbon market. The production of biogas provides the opportunity of developing a new chain of residues from agriculture management (Scarlat et al. 2018). The biogas technology has an important economic, environmental, and social significance; however, there is a scarce acceptance in some rural areas of the developing countries.

While biogas for rural energy is affordable, the construction, the operation, and the high investment present complication, and it has led the farmers to develop cheaper systems. Therefore, the technology installation is one of the barriers, and the investment is out of the financial budget from developing countries. Nevertheless, the installation costs of the biogas plants could be reduced by the government support providing subsides and programs. The market is potentially higher when countries have positive policy frameworks, programs, and financial support when biogas is produced for its general use (Scarlat et al. 2018; Surendra et al. 2014; Rajendran et al. 2012).

The countries developed in policies for the regulation of renewable energies from the AD process are mainly those with greater agricultural performance, where their main objective is the reduction of GHG. Policy implementation improves the biogas plant application by enabling the use of new materials for the plants, the process optimization, and the increase of biogas generation and gas uses. Policies can be classified according to the implementation of the AD as shown in Fig. 3. Table 2 shows some policies and their implementation in developed countries (Hoo et al. 2017).

4.1 United States

The development of the implementation of AD in the USA as renewable energy has been very slow over the years; however, by 2015, 2100 plants were operating. In this country the Renewable Energy for America Program provides loans for AD systems

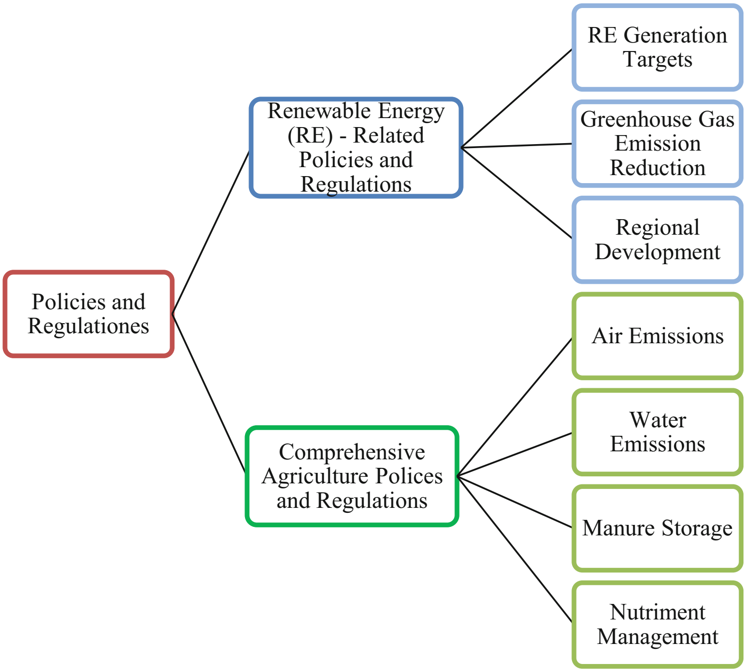

Fig. 3 Policies and regulations to the implementation of AD (Vasco-Correa et al. 2018)

in rural areas. For this sector, the USA has the Clean Water Act that provides greater promotion to the AD (Vasco-Correa et al. 2018). In addition, some activities have laws that help regulate waste; therefore, these laws promote the use of AD as an alternative for its treatment (Edwards et al. 2015).

4.2 European Countries

The different forms of regulation and policies propose goals to promote the production of energy from biogas. The European Parliament's is interested in the renewable energy production growing the policies for the investment on the generation of renewable energy offering funding for new biogas projects. Europe biogas production by the year 2030 is estimated to have the capacity of 18–20 billion m^3, which will correspond to the European consumption decreasing the GHG emissions as the main concern (Lara Grando et al. 2017). European governments mostly offer attractive initiatives to incentive the biogas sector, and the policy on each country is decisive. The tariff for biogas production depends on its capacity and the end use of biogas generation, but it certainly favors the production. For example, in Austria the biogas production from agriculture ranges from 0.13 €/kWh to 0.185 €/kWh (Ferreira et al. 2012).

Table 2 Biogas utilization and policy enforcement based on countries' socioeconomics (Hoo et al. 2017)

Category	Biogas utilization	Countries	Purpose	Project/program/ policy	References
Least developed countries	Heat generation, cooking services	Bangladesh	Environmental benefits (63% average frequency) and economic (59% average frequency) benefits	National Domestic Biogas and Manure Program (NDBMP)	Kabir et al. (2013)
Developing countries	Heat generation, cooking services	China	Energy saving	Biogas digesters at Lianshui and Guichi China	Xiaohua et al. (2007)
	Heat generation, cooking services	India	Government's policy to deliver renewable energy services to households across the countries	National Biogas and Manure Management Program	Raha et al. (2014)
	Fuel for engine and electricity generation	Malaysia	Policy target to increase renewable energy share to 11% by 2020	Fifth Fuel Policy 2000 National Renewable Energy Policy 2010 Small Renewable Energy Power (SREP) Program Renewable energy incentives Feed-in-Tariff (FiT)	Hashim and Ho (2011)
	Fuel for electricity generation	Thailand	To achieve 14% of all energy needs from renewable resources by 2022	Energy Conservation Promotion Act Renewable Energy Development Plan	Aggarangsi et al. (2013)
Developing countries	Natural gas grid injection	European countries	Contribution on reducing greenhouse gases (GHG) emission; policy target to increase renewable energy share to 20% by individual country members	Intelligent Energy for Europe (IEE)	Strauch and Singhal (2013)

(continued)

Table 2 (continued)

Category	Biogas utilization	Countries	Purpose	Project/program/policy	References
	Vehicle fuel	Sweden	To impose profound societal structural change in combating climate change	Swedish Transport Policy	Fallde and Eklund (2015)
	Food waste management	Japan	To reduce greenhouse gases emission	Future Energy Policy Feed-in Tariff Scheme for Renewable Energy	Matsuda et al. (2012)

4.3 Asian Countries

The Asian sector has many strategies for the increasement on the investment for the renewable energy sector to promote the construction of biogas plants in rural areas. In the period from 2001 to 2012, China provided 4.86 billion dollars from government funds for biogas development. In 2009, the "Renewable Energy Law" was amended and was estimated to have the capacity to develop 15% of the energy by the year of 2020, investing 180 billion in renewable energy from this renewable energy policy. The investment by subsidies and law implementations increase 10%, and the installations of biogas were 2.2% higher (Wang et al. 2016).

A Sino-German project (Resource Recovery of Bio-organic Municipal Waste) which is a cooperation platform between China and Germany to integrate an efficient biogas generation focused on the urban and agricultural area estimating the generation of 6 GW_{tot} of BMW-derived biogas generated until 2020 and 25 GW_{tot} until 2050 (Yousuf et al. 2016).

In India the concern on waste management and climate change held to develop new policy initiatives enabling strategies to set up more institutions and laws related to renewable electricity and its enhancement. The creation of the Indian Renewable Energy Development (IREDA), as a Non-Banking Financial Institution, under the administrative control of Ministry of New and Renewable Energy (MNRE) impulse the way for the biomass sector along with the renewable sector to get strong institutional support in terms of finance (Singh and Setiawan 2013). The 40% of the biogas plants, which is five million of plants approximately, were installed under the biogas development program by the MNRE. Moreover, 400 biogas plants were installed for the capacity of 5.5 MW (Mittal et al. 2018).

In 1992, Thailand created the Energy Conservation Promotion Act and programs on energy issues, adding renewable and rural energy. With this plan, energy savings of 33.4Mt are expected in 2030 (Aggarangsi et al. 2013). Based on funding by the Energy Conservation Fund, Thailand promoted biogas generation with the biogas project to promote power generation on livestock farms, which started in 1995 and were divided into four phases until 2013, where the government provided subsidies for the construction of biogas plants on farms for the use of its waste, extending to the use of wastewater (Aggarangsi et al. 2013).

5 Public Policies of Developing Countries for the Implementation of Biogas Systems

The developing countries have sources of energy as the main activities for their economic growth. It has been shown that power generation and its consumption can improve the competition with other countries and the economic growth of developing countries. However, obtaining different types of energy has effects on social, economic, and environmental aspects (Fig. 4) (Amigun et al. 2011; Jan and Akram 2018).

The manufacture of fuels as a source of energy is one of the largest services that provide a greater economic gain in the developing countries. However, this can cause severe environmental damage for the GHG emissions. The production of biofuels is one possible solution that is taking advantage of agricultural waste and reduces the energy production costs, in comparison with other fuels. One of the well-known processes for generating electricity is the implementation of biogas systems (Amigun et al. 2011).

The biogas production from agriculture residues, industry, and municipal residues are attractive options to rise the global economy for developing countries. Some developing countries as Pakistan and African countries, among others, have implemented the installation of biogas systems as a new alternative to take advantage of disused agro-industrial waste and reduce energy production costs.

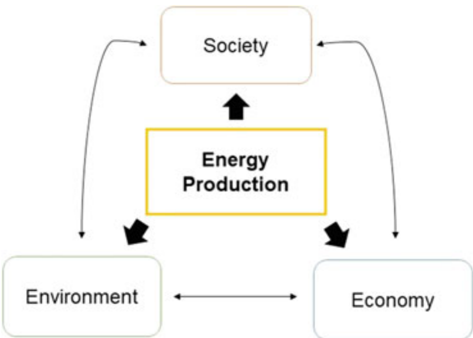

Fig. 4 Relation between effects by energy production in developing countries (Amigun et al. 2011)

5.1 African Countries

Africa is one of the developing countries with a large livestock population and agricultural areas. Because of this, it makes it a highly competitive country for the use of waste as the main source of sustainable energy generation. However, in 2014 only 38% of its population had access to electricity service (Bos et al. 2018). For this reason, the implementation of biogas systems for the use of waste and energy generation has been developed in many of their countries. However, the biogas installations launched so far are family sized (Cheng et al. 2014).

The government of the African continent, over time, has implemented new policies and support for the generation of renewable energies. Of the 56 countries that make up this continent 45 manage to have some law corresponding to the support of the implementation of these energies (Renewable Energy Network 2018). The South African government in 2009 managed to introduce a plan for renewable energy projects. However, this was not carried out due to opposition from the state power company (Becker and Fischer 2013).

Ghana has a large number of policies for the implementation of sustainable energies. One of them is the National Electrification Scheme (NES) implemented in 1989 which was extended until 2020. This policy deals with the purchase of renewable energy to promote the development of biogas systems (Kemausuor and Ackom 2017).

Nowadays Nigeria country keeps a strictly energy polices named National Renewable Energy and Energy Efficiency Policy (NREEEP), implemented since 2014 by the Energy Commission of Nigeria. A part of this policy includes the manufacture of biogas systems of various designs to support domestic, industrial, and institutional energy. So far with this law, 500 short-, 6000 medium-, and 8000 long-term digesters have been implemented (NREEEP 2014).

However in East Africa, Tanzania is the only country that have policies to support biogas systems through phase I investment subsidy in 2015 (Clemens et al. 2018).

5.2 Latin America

Countries within Latin America have great potential in biogas generation. However, the development of these systems has been slow compared to other developing countries. In 2009 the Network for Biodigester in Latin America and Caribbean (RedBioLAC) was created. This Network has been of great use, as it has promoted the installation of domestic biogas systems in Latin countries such as Bolivia, Costa Rica, Ecuador, Mexico, Nicaragua, and Peru. Bolivia leads these countries with 1000 functional biogas plants installed (Alemán-Nava et al. 2015; Garfí et al. 2016).

As for the installation of industrial biogas systems, 127 plants have been installed in Brazil, generating 584 billion m^3 of biogas per year. In addition, some other countries such as Colombia, Honduras, and Argentina have started with the construction of large-scale biogas plants due to RedBioLAC (Vögeli et al. 2014).

Also, global biogas production in 2017 as an electricity harvest was 31 million m^3, which 65% tested from the Asian continent and about 33% was produced in Latin America (Zervous 2019).

In México, the policies implemented by the federal government are expected to produce 4.8% of the renewable electricity used in the country in 2028. Mainly, the highest waste for biogas production in the states of Mexico is cow manure, organic waste, and wastewater (Díaz-Trujillo and Nápoles-Rivera 2019). Also, in 2050 the Mexican government foresaw greenhouse gas emissions to decline approximately 50% with the implementation of appropriate biogas systems. In addition, México is the only country in Latin America to provide credits to renewable transport fuel suppliers in order to use fuels from the generation of biogas, by the process of AD to gas-powered vehicles (Global Methane Initiative 2014). Although these countries possess a high capacity for the production of biogas systems, the lack of government support has restricted the developed of fully biogas systems.

Currently, some Mexican public policies related to the implementation of biodigesters for methane mitigation are carried out. The "Programa Especial de Cambio Climático" (PECC 2014–2018) has an advance of 76.12% and is based on an inclusive sustainable development model that incorporates the transition to a low carbon economy. Especially in the strategy 4.2, it is mentioned how to reduce methane emissions in wastewater treatment plants, sanitary landfills, and the oil and agriculture sectors through the construction of biodigesters. Nowadays, the implementation of the PECC 2020–2024 is beginning; however no progress has been reported (SEMARNAT 2014).

Other public policy is the "Programa Sectorial del Medio Ambiente y Recursos Naturales" (PROMARNART 2019–2024), which promotes the construction of biodigestion plants of organic waste (PROMARNART 2019). The "Estrategia Nacional de Cambio Climático vision 10-20-40" is another national policy and projects long terms to face the effects of climate change and to move towards a low carbon economy. One of its strategies is to implement energy efficiency actions such as promoting biodigesters (INECC 2015). However, although this country possesses a high capacity for the production of biogas systems, the lack of government support has restricted the developed of fully biogas systems.

5.3 Pakistan

Pakistan is the sixth most populous country in the world. According to the World Bank Group database in 2018, it had 212.22 million people, and more than 50% of the population live in rural areas. For this reason, the government implemented new policies to improve the growth and its economy in this sector. This country has about 175 million head of cattle, which produce about 650 million kilograms of manure a day. Farmers began to use these wastes, burning them for domestic purposes and by creating electricity and caloric energy from biogas systems. However, there is still lack of knowledge about the exploitation of natural carbon sources from waste due this amount of manure, used properly, which could generate about 16.3 million m^3 of biogas per day, being a great opportunity for the country's economic increase (Amjid et al. 2011).

In 2000, the government of Pakistan initiated a Biogas Support Program (BSP), thus installing 1200 biogas units. With a future perspective to implement around 10,000 more biogas units in the next years, it will be possible to take advantage of approximately 30% of the emissions formed by livestock waste. The objective of this program is to reduce the deforestation and to increase the agricultural production through biogas systems (Ilyas 2006). This program has only been implemented for animal waste; however there is also knowledge of food waste and paper industry, which are not still included by the government support (Ilyas 2006; Amjid et al. 2011; Jan and Akram 2018).

5.4 *Biogas Systems Challenges in Developing Countries*

Unfortunately, in developing countries there are a wide range of challenges for the implementation of biogas systems (Fig. 5) (Patinvoh and Taherzadeh 2019). Inadequate infrastructure and poor technical training for the operation of biogas systems are one of the main causes, making these systems have low biogas production (Gebreegziabher et al. 2014). The scarce knowledge of the performance of

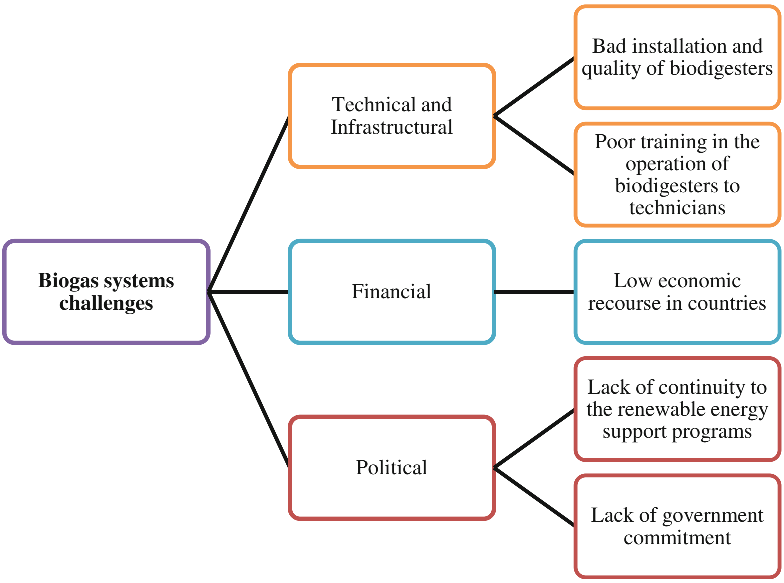

Fig. 5 Biogas systems challenges on developing countries

biodigesters and the poor installation result in the digester malfunctioning, as well as the zero domestication and industrial service of the energy generated by the industrial services (Surendra et al. 2011; Patinvoh and Taherzadeh 2019).

Countries with low economic resource are another challenge. Domestic biodigesters may be somewhat of low quality, and a treatment for biogas purification is required. Only a domestic biodigester comes to cover about $1500 per day and those of industrial scale about $500,000–$1,000,000 (Morgan et al. 2018). Policies about the implementation of biogas systems, transport, and waste collection by this system are null or not carried out in developing countries. In addition, the lack of government commitment and the intermitent continuity to renewable energy support programs have contributed to the poor current level of biogas technology (Akinbomi et al. 2014).

6 Perspectives

In many ways, biogas is a serious alternative to other fossil resources and a complement to other renewable energy sources as wind and solar. However, biogas production technology still has a high potential to improve its efficiency in the production process. This is due to the fact that biogas and other end products have a significant disadvantage: production costs remain relatively high, despite of a wide range of progress (Bahrs and Angenendt 2019).

Although there is already a several applications of biogas technologies worldwide, the industry is still in its early stages of development. World Biogas Association proposes that the biogas industry can be analyzed in three broad categories: micro-digesters that use biogas, scale digesters that generate electricity, and large-scale digesters that produce biomethane (Jain 2019).

6.1 Micro-digesters

Micro-digesters play a very important role in rural areas of developing countries, where they are an integral part of agriculture, waste management, and energy security. There is a total of about 50 million microscale digesters that operate worldwide. The biogas from these digesters is most often used for cooking or heating, displacing high-emission solid fuels such as firewood and coal.

6.2 Digesters to Scale

Scale digesters are mainly used for electricity generation. This is a technology that is widely used throughout the world. Operators of biogas plants at scale are trying to maximize efficiency and input flows by increasing heat utilization. The global generation of electricity from scale digesters reached a growth of 90% compared to 2010, generating 87,500 GWh in 2016.

6.3 Medium- to Large-Scale Digesters

Obtaining biomethane from biogas is a relatively new technology and is mainly used in local and national networks as fuel. While CO_2 is also used, in greenhouses and in the food industry, it is estimated that, worldwide, there are 700 plants that upgrade the biogas to biomethane.

6.4 Biogas Production in the World

In developing countries, biogas production is mainly on a domestic scale, to obtain fuel used in the kitchen or as lighting, compared to developed countries where it is focused on large-scale biogas plants, based on farms, electricity, and heat (Scarlat et al. 2018).

6.4.1 Asia

Several countries in Asia, such as China, Thai, India, Nepal, Vietnam, Bangladesh, Sri Lanka, and Pakistan, have programs for national biogas production, where support is given to develop domestic systems to provide the population with alternative energy sources.

Nepal has one of the most successful biogas programs, with more than 330,000 domestic biogas plants installed under the Biogas Support Program. Bangladesh opened the National Biogas and Domestic Manure Program in 2006 for rural areas that resulted in 36,000 biogas digesters at the end of 2014, the installation of 130 commercial digesters in 2017 and the construction of 100,000 small biogas plants by 2020 (Adib et al. 2015). China had an estimated 100,000 modern biogas plants in 2014, generating approximately 15 billion m^3 of biogas, equivalent to 9 billion m^3 of biomethane. Thus, with the Medium and Long Term Renewable Energy Development Plan, it plans to reach around 80 million biogas plants in homes by 2020, 8000 large-scale biogas projects, and an annual biogas production of 50 billion m^3 (Scarlat et al. 2018).

6.4.2 Africa

In Africa, despite being a poorly developed region in biogas production, the Biogas Association Program, with the support of the Netherlands Ministry of Foreign

Affairs, aimed at developing national biogas programs in Ethiopia, Kenya, Tanzania, Uganda, and Burkina Faso, for the construction of 100,000 domestic digesters. Currently, the African "Biogas for a better life" initiative aims to provide two million domestic biogas digesters by 2020. With this support, it has been estimated that the technical potential of biogas in Africa allows the construction of 18.5 million plants biogas domestic (Austin and Morris 2012; Marro and Bertsch 2015).

6.4.3 America

In 2017, the USA had more than 2100 biogas plants: 250 use cattle manure, 654 were biogas recovery plants from landfills and about 1240 wastewater treatment plant operated anaerobic digesters producing biogas (Scarlat et al. 2018). On the other hand, Latin America has both agricultural and domestic biogas plants. It has the Network for Biodigesters in Latin America and the Caribbean that promotes the development of small biodigesters in countries such as Mexico, Peru, Cosa Rica, Ecuador, Nicaragua, and Bolivia, where the latter has 1000 domestic biogas plants installed (Vögeli 2014; Persson and Baxter 2015).

6.4.4 Europe

In 2015, the European Union had more than 17,400 biogas plants, ranging from small anaerobic digesters on farms to large co-digestion plants, where total biogas production reached more than 18 billion m^3. Biogas production in Europe has grown significantly in recent years, mainly due to the support schemes established by the member countries of the European Union. The greatest contribution of biogas comes from anaerobic digestion, which is carried out mainly in countries such as Germany, Italy, Czech Republic, and France, followed by biogas from the recovery of landfill gases, where the UK, Italy, France, and Spain are the main producers. Meanwhile, biogas from wastewater treatment predominates in a few countries, such as Sweden, Poland, and Lithuania (Van Foreest 2012; Scarlat et al. 2018). The Green Gas Grids Project expects by 2030 a production of between 48 and 50 billion m_3 per year of biomethane (EBA 2013).

Güsewell et al. (2019) raised future perspectives for Biogas Plants determined mainly by the following aspects:

- Existing biogas plants continue to show a high cost of electricity even after depreciation of the main components. This is mainly due to the high cost of continuous capital for the replacement of technical components.
- High costs of biogas production caused by the cultivation of energy crops. A considerable reduction in costs seems unlikely due to competition in the use of biomass in different sectors and the increase in the means of production.
- The constant need for adjustments and modifications of biogas plants is due to new functions such as flexible energy generation (flexibilization) to balance the increasing quotas of fluctuating renewable electricity and the implementation of

new legal requirements in the agricultural sector such as the ordinance of fertilization.
- Continuous replacements and optimization measures are required due to the breakdown, the projected end of life and the technical progress of the components of the biogas plants.

These adjustments and measurement are considered under the term “repowering,” which is defined as the replacement of old power plants or central components to increase the efficiency rate or capacity of the plant and reduce greenhouse emissions. Although there is already a wide application of biogas technologies worldwide, the industry is still in its early stages of development.

Economics and governmental policies are the key determining factor that affects the development of biogas production. However, the ability to produce energy resources while treating waste streams and mitigating greenhouse gas emissions makes anaerobic digestion technology very popular. Biogas can play an important role in the future as an energy carrier because it is flexible in use and is storable, which makes it very valuable for balancing energy networks. With the constant increase in the price of crude oil in recent years, process integration could be an important area to make it economically more attractive. Biogas production could increase from prolonged use of various flows of organic waste, such as food waste, crop residues, sewage sludge, or microalgae sludge.

7 Conclusions

Government policies in terms of AD are directly influenced by the factors of interest in each country, mainly agricultural and environmental factors that lead to the production of biogas, taking advantage of the opportunity of its conversion to energy as an economical strategy. In some countries, it is possible to produce up to 90% of energy for consumption; in addition, this alternative presents the use of agricultural residues, mainly reducing the environmental impact. Thus, policies play a major role in planning strategies for energy generation in the energy sector, which also impacts in reducing the GHG emissions in the atmosphere. The implementation of the policies promotes integrated technologies, turning AD as an alternative to energy generation and boosting the economic growth in developed and developing countries.

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