Chapter 11
Appropriate Biochemical Conversion Technology for Organic Waste Recovery in Developing Countries

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11.1 The Biochemical Biomass Conversion Technologies

Growing energy consumption, increasing fossil fuel trends, escalating fuel prices, and rising levels of CO_2 and other greenhouse gases are some of the main drivers for the search for alternative energy sources (Nanda et al. 2016). Numerous biomass conversion technologies are used to valorize all components of a raw material. These technologies include a wide spectrum of biological/biochemical processes to generate products such as biofuels and value-added products. These processes are generally defined as fermentative, although each of them requires specific operating conditions (e.g., anaerobic environment, light supply) and/or specific microorganisms (bacteria, yeast, cyanobacteria, algae) (Gouveia and Passarinho 2017).

11.1.1 Anaerobic Digestion of Biomass

Every year, millions of tons of biomass waste are produced, with disposal posing a challenge. Over 88% of the world's electrical and thermal energy consumption is met by non-renewable resources, namely petroleum and natural gas (Ziemiński and Frąc 2012). Anaerobic digestion (AD) is a biological process that uses anaerobic bacteria to degrade organic substrates in an oxygen-free environment. The end-products of AD are biogas and residue named digestate. The biogas contains mostly

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of methane and is considered as a renewable energy (Bakraoui et al. 2020b; Lahboubi et al. 2021).

The conversion of cellulose and hemicellulose to bioethanol, methane, and hydrogen is more efficient when the digestibility of lignocellulosic biomass is improved (Boontian 2014). The AD process is a potential process for digesting biomass waste into large amounts of methane, which can be utilized directly as a source of energy or converted to hydrogen (Albertson et al. 2006). Due to current environmental issues, such as global warming, high-rate methane and hydrogen fermentation from renewable biomass has received a lot of interest recently (Demirel et al. 2010). Figure 11.1 shows the process of AD from different organic wastes. The by-products of AD are biogas and digestate (Beniche et al. 2021; Habchi et al. 2022). The biogas is used to produce thermal or electrical energy and also the biofuels, and the digestate is used as fertilizer for the soil and can also be used by the thermochemical conversion. Methane production can be improved using different pretreatment methods (Lahboubi et al. 2022; Habchi et al. 2022) or by co-digestion (Beniche et al. 2020; Karouach et al. 2021).

11.1.1.1 The Stages of Anaerobic Digestion

It is critical to know and understand the process, technological elements, biochemistry, and microbiology of AD in order to ensure proper design and implementation of anaerobic treatment systems. Several sequential, simultaneous, and complex biological and chemical reactions are involved in the AD process. The substrates of one group of microbes are the products of the next.

Anaerobic degradation is divided into four stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Kerrou et al. 2021). Various microorganism populations are involved in the degrading process. Different steps in the biosynthesis of methane can be distinguished according to the substrates utilized by these bacteria and the products they create (Moletta 2006). They are shown in the diagram below Fig. 11.2.

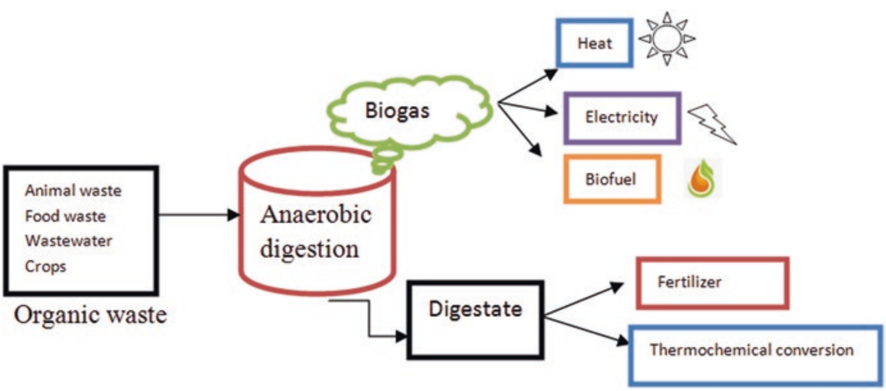

Fig. 11.1 The process of anaerobic digestion

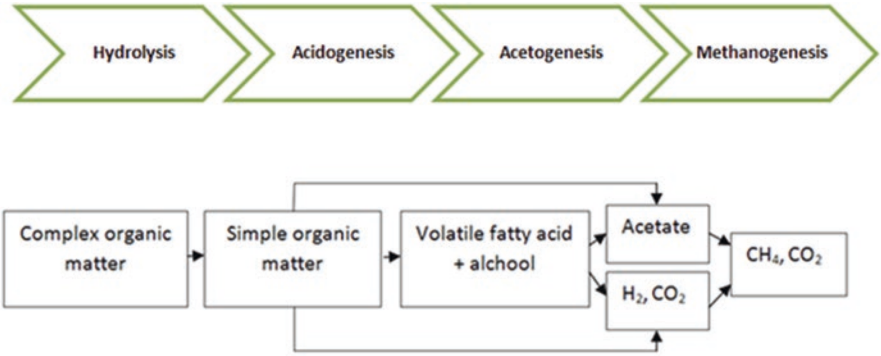

Fig. 11.2 The stages of anaerobic digestion

Hydrolysis

Hydrolysis is an extracellular process that converts complex polymers (proteins, polysaccharides, lipids, cellulose, and soon) that are inaccessible to microbes into simple, soluble molecules (amino acids, simple sugars, fatty acids, glycerol, etc.). As a result, the hydrolysis process seeks to break down organic macromolecules into smaller components that acidogenic bacteria can utilize (Ostrem 2004).

Acidogenesis

The acidogenesis stage entails the conversion of monomers from the hydrolysis stage into a variety of chemicals, including organic acids, volatile fatty acids (VFAs), alcohols, hydrogen, carbon dioxide, ammonium, and so on. There are two types of acidogenesis: hydrogenation and dehydrogenation. Acetates, CO_2, and H_2 are the primary transformation products, with additional acidogenesis products playing a minor role (Chynoweth et al. 1998). The methanogenic bacteria could employ the new products as substrates and energy sources immediately after these changes. The bacteria's response to an increase in hydrogen concentration in the solution is the build-up of electrons by molecules such as lactate, ethanol, propionate, butyrate, and higher volatile fatty acids. The novel products are incompatible with methanogenic bacteria and must be transformed by obligatory hydrogen-producing bacteria in a process known as acetogenesis (Ziemiński and Frąc 2012).

Acetogenesis

The action of acetogenic bacteria permits the transformation of acids produced during the acidogenesis phase into acetic acid, hydrogen, and carbon dioxide during the acetogenesis stage. Acetic acid is particularly significant in methanization since it can account for up to 70% of the methane generated (Ntaikou et al. 2010). The oxidation of the substrates (propionic and butyric acids, as well as ethanol) is accompanied by the generation of acetate, hydrogen, and carbon dioxide at this stage. Two species of bacteria are involved in this process:

- Hydrogen-producing bacteria (OHPA) are anaerobic bacteria that produce hydrogen ("obligate hydrogen-producing acetogens"). They can make acetate and hydrogen from decreased acidogenesis products like propionate and butyrate. It is worth noting that these bacteria have a considerable multiplication time, ranging from 1 to 7.5 days.

- Non-syntrophic acetogenic bacteria: these bacteria's metabolism is primarily focused on the generation of acetate. They thrive in high-CO_2 conditions, which are common in anaerobic habitats. Non-syntrophic acetogenic bacteria are divided into two categories.
- Bacteria that create acetate, butyrate, and other chemicals from simple sugars make up the first category. Acetate is made from hydrogen and carbon dioxide.

Methanogenesis

Methanogenic archaea transform the products of the previous stage into methane and carbon dioxide in this final step. To create methane, they fundamentally use acetate, formate, carbon dioxide, and hydrogen as substrates. There are two main mechanisms for methane generation for this purpose, both involving strict anaerobic archaea (Moletta 2006):

- Acetoclast methanogens: Acetate + $H_2 \leftrightarrow CO_2 + CH_4$
- Hydrogen-trophic methanogens: $CO_2 + 4H_2 \leftrightarrow 2H_2O + CH_4$

In anaerobic digesters, about 60–70% of methane is produced by acetoclast methanogens (Batstone et al. 2002).

11.1.1.2 Operating Conditions for Anaerobic Digestion

Several factors influence AD, including the physical system and biogas generation (CH_4 and CO_2). It is therefore critical to keep the experiment under controlled circumstances in order to produce a decent biogas yield.

To ensure process stability, the following parameters can be managed and maintained at acceptable intervals. Temperature, pH, alkalinity, residence time, waste composition, and inhibitor presence are all factors to consider. The relevance of each parameter must be understood because any variation from the permissible range can cause the system to shut down.

Temperature

Temperature is a crucial element in biological processes because it impacts microorganism growth kinetics and material transfer. AD requires continuous environmental conditions, preferably close to the process optimum, to get the best biogas yield. Frequently, a significant portion of the biogas produced is used to provide process energy. The anaerobic digester can be heated via coupling solar energy and biodigester (Ouhammou et al. 2019). According to the authors, the coupled system provides a 100% reduction in energy usage for nearly 10 months of the year and a 70% reduction for 2 cold months. Microorganisms are categorized into three types based on the temperature range in which they can proliferate (Cresson et al. 2006). The temperature phases are as follows:

- Psychrophilic: T < 20 °C
- Mesophilic: 20 °C < T < 45 °C with optimum for 35 °C
- Thermophilic: 45 °C < T < 65 °C with optimum for 55 °C

pH and Alkalinity

pH is an essential parameter in AD because each of the microbial groups involved in the reactions has a specific pH range for optimal growth. It is therefore important to monitor the pH and, if necessary, adjust it in the feed or automatically regulate it in the digester. The optimum pH for AD is around neutral, between 6.5 and 8.5 (Lahboubi et al. 2020). If the acceptable operating range of a reactor is between 6.5 and 8.5, the ideal values for methanogenic microorganisms vary between 7.0 and 7.2. A drop in pH below 5.0 is lethal to these organisms. The use of pH as an indicator of the process is normally based on the fact that a drop in pH corresponds to the accumulation of VFA (Bakraoui et al. 2020a). An important element in maintaining pH is the alkalinity of the digester (Wilson 2004).

Alkalinity (Alk) measures the buffering capacity in the digester and thus its ability to maintain a stable pH (Batstone et al. 2002). Alkalinity is usually expressed in terms of equivalent calcium carbonate concentration (mg CO_3Ca/L). An alkalinity value greater than 1000 mg CO_3Ca/L is recommended so that methanogenic populations are not inhibited. It should be noted that pH and alkalinity in an AD system are affected by the concentration of CO_2 in the upper void space of the digester (in the biogas) (Wilson 2004).

Volatile Fatty Acids

One of the most essential markers in monitoring the AD process is VFA concentration. Acidogenic and acetogenic bacteria create VFAs, which are then eaten by methanogenic bacteria). It is widely assumed that their concentration in the digester indicates a methanation process fault (Wilkinson 2011). It is widely assumed that their collection in the digester indicates a digestive process dysfunction. The main cause of toxicity and reactor failure in the AD process is the reduction in pH that occurs as VFAs accumulate (Hill and Bolte 1989).

Retention Time

The retention time (RT) also known as residence time is the amount of time the substrate spends in the reactor on average. It is determined using the volumetric loading rate of a reactor while it is in operation. A longer retention time should theoretically result in a more complete deterioration of the feedstock. The reaction rate, on the other hand, diminishes as retention duration increases (Boe and Batstone 2005). Each type of substrate has a different retention period, which spans from 14 to 30 days for most dry procedures to as little as 3 days for wet processes. According to a research, a decrease of 64–85% of volatile matter in a reactor can be achieved in less than 10 h for specific wastes; however, the retention time is longer (Sakar et al. 2009).

Organic Loading Rate

The pace at which organic matter can be delivered into a digester is known as the organic loading rate (OLR). Overloading could lead to system failure due to the accumulation of inhibitory chemicals; hence the OLR is an important control parameter in AD. In this situation, the system's feed rate should be lowered (Lettinga 2001).

Figure 11.3 resumed the most important parameters (Alk, T, pH, OLR, RT, and VFA) of the AD control.

Fermentation of Biomass

The current global energy picture emphasizes nonconventional energy sources. Biomass has established itself as a reliable unconventional feedstock for bioethanol production (Khan and Dwivedi 2013). Biomass resources are classified into four groups around the world. Wood scraps are currently the most abundant biomass source for energy production. It comes from the paper mills, sawmills, and furniture making industries. Agriculture residues and dedicated energy crops are the next largest, followed by municipal solid trash. Dedicated energy crops appear to be the greatest and most promising future biomass resource among these biomass resources, which include short-rotation woody crops and herbaceous crops, especially tall grasses. This is due to the potential to get several harvests from a single planting, which lowers the average annual cost of establishing and managing energy crops dramatically, especially when compared to traditional crops.

In some emerging nations, the production of fuels, chemicals, and power from trees, crops, and agricultural and forestry wastes is already underway. Executive orders have been passed to exploit such resources for the development of clean energy in several wealthy nations as well (Shah and Rehan 2014).

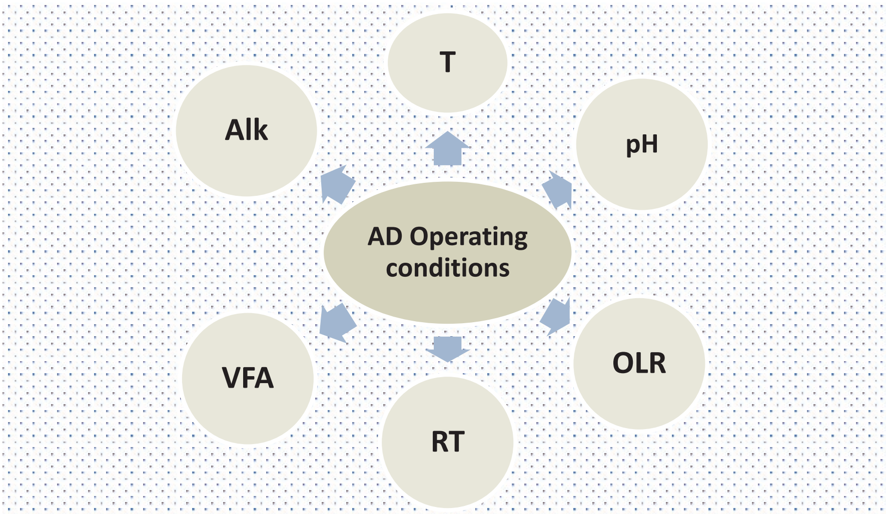

Fig. 11.3 Anaerobic digestion operating conditions

11.1.1.3 First-Generation Bioethanol Production

First-generation biofuels are made from biomass that is commonly utilized in the food industry, such as corn, soy, and sugar cane. These biofuels are created by fermenting or chemically converting the oils, sugars, and starches found in biomass into liquid fuels. Bioethanol production utilizing first-generation feedstock is a well-established technology with high bioethanol productivity and output; the method is associated with the food-to-fuel controversy and a high environmental effect due to land use charge (Ayodele et al. 2020). Moreover, an integrated biorefinery technique can be used as an efficient strategy to lower the bioethanol minimum selling price in half, according to a techno-economic analysis published in the literature by Aghaei et al. (2022) on the production of bioethanol from corn stover residue by applying pretreatment techniques. The saccharification and fermentation pretreatments showed their positive effect on the first-generation bioethanol production process in terms of yield and cost. Figure 11.4 depicts the bioethanol manufacturing process using sugar-based feedstocks high in sugar or starch that are fermented to produce bioethanol.

In order to meet the Kyoto Protocol's carbon dioxide reduction targets and lessen reliance on the supply of fossil fuels, governments around the world have carefully considered and directed state policies toward the improved and affordable utilization of biomass for meeting their future energy demands. Brazil and the USA produce the majority of the world's bioethanol, contributing 26.72% and 56.72%, respectively (Gupta et al. 2015).

Assessing the sustainability of first-generation bioethanol is not an easy task, as it depends on several factors related to the economic situation of the country in terms of food security and agricultural activities.

11.1.1.4 Second-Generation Bioethanol Production

In order to produce second-generation bioethanol, a wide range of non-edible agricultural and industrial lignocellulosic wastes are used, such as rice husk, wheat straw, maize stalks, olive pomace, bagasse, coconut husk, paper pulp industry waste, and even fruit peels.

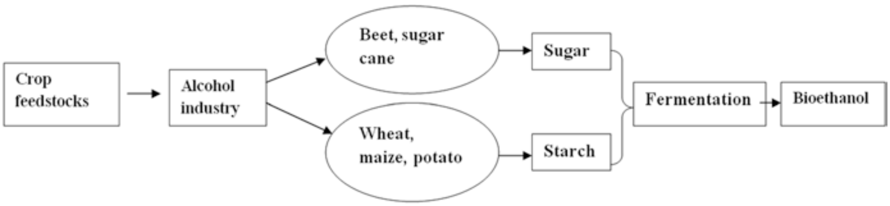

Fig. 11.4 First-generation bioethanol production

Table 11.1 Composition of the sugar cane molasses

Water content, %	Soluble solids content, %	Total sugar, %	Total nitrogen content, %	Mineral substances content, %	pH	References
18,2	81,8	54,6	0,5	6,2	7,6	Elena et al. (2009)
18,85	81,15	48,87	0,90	13,82	5,3	Hashizume et al. (1966)
–	88,67	51,36	0,39	10,45	5,1	Hassan et al. (2019)

Agricultural waste can be exploited, and the demand for fossil fuels can be alleviated, in particular, molasses, a by-product obtained during the refining of sugar cane (Ghorbani et al. 2011). In the commercial production of bioethanol, manufacturers most often use sugarcane molasses as feedstock because of its abundance and low cost. The most commonly used microorganisms for fermentation are *Saccharomyces cerevisiae* yeasts because of their ability to hydrolyze sucrose from sugarcane molasses into glucose and fructose and too easily identifiable hexoses (Elena et al. 2009). Molasses has been of great interest for bioethanol production because it is cheap, rich in sucrose, which is a substrate that does not require pre-treatment before fermentation (Bouallagui et al. 2013). Table 11.1 presents the composition of the sugarcane molasses; we notice that the sugar content is higher than 50% for the three examples presented. That means it is a suitable feedstock since the sugar is a key element for the bioethanol production.

In Pakistan, bioethanol produced from sugarcane molasses has been evaluated for its potential for availability, energy efficiency, and environmental sustainability. The current potential of molasses-based bioethanol was found to be sufficient to replace about 7% of the nation's total gasoline usage. Pakistan is the eighth largest producer of sugar in the world and the fifth largest producer of sugarcane (Ghani and Gheewala 2021).

In Mexico, an estimated yearly need of 3 billion liters is expected to be produced primarily from sugarcane, knowing that bioethanol is now being introduced as a fuel oxygenator (Lopez-Ortega et al. 2021). This study shows how the Brazilian experience gained over 40 years of successful transformation of its biorefinery sector. This long experience could be used to transform the Mexican sugar industry by redeveloping sugar mills to produce bioethanol from molasses first and then using juice to sustainably increase bioethanol production (Lopez-Ortega et al. 2021).

11.1.2 Sustainability of Second-Generation Bioethanol Production

Increasing energy demand, growing debates about whether first-generation biomass should be used for food or fuel, and market pressure for environmental sustainability are forcing bioethanol supply chain decision-makers to use non-edible second-generation biomass feedstocks while reducing carbon emissions. Most biofuel manufacturers now use edible first-generation biomass feedstocks. Motivating them to move to a second-generation feedstock, from both an economic and environmental standpoint appears to be critical in this context (Esmaeili et al. 2020a). From a sustainability standpoint, first-generation biofuels have both benefits and drawbacks in terms of environmental and socioeconomic implications.

In African case, for several reasons, the bioethanol business has been rapidly expanding for use as an alternative motor fuel. This sector of the economy is still developing in South Africa (Amigun et al. 2011) (Table 11.2).

The production of bioethanol is in direct function with the raw material used. For Brazil, it uses sugar cane as raw material to produce bioethanol; the production was 44.9% billion liters in 2006 as shown in Table 11.3; this is the most important production compared to other countries. In order to produce an important quantity of bioethanol, the choice of the raw material to be used is a very important step which allows us a good management of the waste more precisely in the developed countries. In 2018, global bioethanol output hit 108.6 billion liters (Table 11.3). The United States and Brazil together generate 84% of the world's bioethanol, with the EU accounting for 5% and China for 4% (Table 11.3). Sugarcane, corn, and sugar beets are the most commonly used crops for bioethanol production (Sydney et al. 2019).

To reduce dependence on fossil fuels, sustainable energy requires renewable energy sources. Corn has been used to make first-generation bioethanol as a renewable energy source. However, the creation of such a biofuel raises corn-based food prices, leading to heated arguments over food vs fuel. First-generation bioethanol producers would be enticed to switch to second-generation bioethanol production by financial incentives (Esmaeili et al. 2020b). Along with better technologies, residues from the second-generation process (e.g., unreacted lignocellulosic material) could be used as fuels, increasing the amount of surplus bagasse. Instead of biodigestion to produce biogas, pentose fermentation to bioethanol will result in increased

Table 11.2 Commercial first- and second-generation biofuels compared at present technology levels

	First generation	Second generation
Source of energy	Starch, sugar, and oil are examples of fuel-producing substances	Mostly lignocellulose is turned into fuel
Source of biomass	Only the principal crop product (e.g., grain, sugar, or oil-seed component of the plant) is used to make the fuel; the rest of the plant is not utilized	Produced from whole plants, crop wastes, forestry residues, or waste from wood processing
Crops	Corn, wheat, sugar cane and sugar beet, rapeseed, oil palm, and soybean are all annuals	Switchgrass, Miscanthus, Coppice Willow, and Alfalfa are examples of perennials
Prospects	N_2O emissions, which are generally doomed, contribute to global warming	Genetic engineering is closely tied to development, and its widespread use endangers food security and exacerbates climate change

Adapted from Ponti and Gutierrez (2009)

Table 11.3 Bioethanol production for different countries

Country	Feedstock	Bioethanol production of 2006[a] (% billion liters)	Bioethanol production of 2018[b] (million liters)
USA	Primarily corn	46.9	60,000
Brazil	Sugarcane	44,9	28,000
Canada	Corn, wheat, straw	0,5	–
China	Corn, wheat, cassava, sweet, sorghum	2,6	–
EU	Wheat, other grains, sugar beets, wine, alcohol	4,1	–
India	Molasses, sugarcane	0,8	–

[a]Ponti and Gutierrez (2009)
[b]Sydney et al. (2019)

bioethanol production, increasing the process' energy demand and, as a result, reducing the amount of excess lignocellulosic material available (Dias et al. 2013).

Bagasse might thus be used for second-generation bioethanol production, with the cogenerated by-product being applied to the soil to create a sustainable second-generation bioethanol production system that improves soil carbon stocks and nutrient bioavailability (Inglett et al. 2021).

Given the drawbacks and benefits of both kinds first and second generations of bioethanol, an integrated approach of both technologies is recommended. Ayodele et al. (2020) reported that combining 2G and 1G bioethanol production in a single facility delivers technological, economic, and environmental benefits, compared to a stand-alone 2G bioethanol production method. Bioethanol synthesis from 1G feedstock has the advantage of producing a lot of bioethanol. However, there are concerns about the food-to-fuel debate as well as significant environmental consequences. Due to the abundance of lignocellulosic biomass resources and its potential as a cleaner and ecologically friendly biofuel, bioethanol production from 2G feedstocks has gotten a lot of attention, but is initial investment and end-product cost still too high. The integrated approach leads to reduce the operational and the end-product cost and to preserve the environment, which makes it a cost-effective and a sustainable approach. In the same context, Ferreira et al. (2018) reported that incorporating second-generation feedstocks into first-generation facilities can have favorable technological, economic, and environmental outcomes. These possibilities can affect waste management by constructing suitable biorefineries and circular economies, in addition to realizing bioethanol production from second-generation feedstocks. This strategy entails enhancing first-generation bioethanol plants by the valorization of intrinsic waste streams, the integration of cogeneration systems, and the incorporation of lignocellulosic materials and other wastes.

In another study related to the same field, conducted by Furlan et al. (2012), based on first- and second-generation bioethanol synthesis from sugarcane, a modeling using a process simulator for four case studies. The results revealed the importance of appropriate bagasse partitioning for the process energy self-sufficiency.

Sugarcane bagasse is currently primarily used to provide electric and thermal energy to the process. The creation of second-generation bioethanol raises heating demands by at least 25%, limiting the decision range for how much bagasse may be redirected to second-generation fuel production. Furthermore, the surplus of electric power has decreased by at least 31%, which might have a significant influence on process economics because it is sold as part of the industry goods portfolio.

Bioethanol manufacturing is currently progressing to the third generation. Third-generation biofuels are made from algal biomass, which has a considerably different growth yield than traditional lignocellulosic biomass. Because of its high protein content and high hexose content (15.29% of the raw material on a dry basis), *Sargassum muticum* is a good feedstock for third-generation bioethanol production (10.55%) (del Río et al. 2019).

It is clear that there are certain criteria that need to be met to improve and optimize bioethanol production. These criteria include, for example, process quality certificates, which guarantee the efficiency of alternative energy sources, and are becoming increasingly popular as a result of the promotion of biofuels, particularly bioethanol, in the industrial or agro-industrial sector. In developing countries, the biggest problems with biofuel production, however, go beyond the consequences of utilizing subpar technology or not relying on its advancement. To increase the production of bio-ethanol sustainably and efficiently, while also balancing the needs of society and the environment, the industrial sector must encourage and implement innovative techniques, tools, and infrastructure. Extensive research and government investments are required to support the best growth of biofuel production. The development of bioethanol needs to be encouraged by tax breaks and financial aid provided to biofuel companies.

11.2 Organic Waste Management and Recovery in Developing Countries

Many developing countries are today confronted with major development issues, which may be aggravated if old development programs are maintained. Following the recent global economic crises, development issues are projected to worsen as a result of the negative impact on rich countries' ability to provide required support to poor countries. Urbanization is accompanied by an increase in the number of people living in cities. The number and complexity of created wastes and overburdens, especially solid wastes, will increase as a result of the growth. The mismanagement of these wastes can damage the environment and lead to different problems. Thus, different developing countries opt to treat solid wastes by specific treatment, according to the nature and characteristics of the waste, to produce valuable product that can be used.

11.2.1 Appropriate Biogas Technology for Developing Countries

In developing countries, the common digesters implanted are the fixed dome (Chinese type), floating cover (Indian type), and a balloon digester (Fig. 11.5).

Figure 11.5 shows the common applications of biogas used in the developing countries. The use of biogas in these countries is restricted to cooking and lighting. In Syria, the size of digesters implanted is between 14 and 100 m^3, with an annual production of 4.6 billion m^3 of biogas and 341 million tons of high quality organic fertilizer (Jafar and Awad 2021). In Nepal, more than 431,000 biogas digesters family sizes (4–10 m^3) were installed with an annual biogas production of 3.04 billion m^3 (Lohani et al. 2021). Farmers with a medium or high income were more likely to adopt the technology than lower farmers income (Mwirigi et al. 2009).

In fact, different studies in the literature suggest that food waste (FW) can produce biogas using AD processes as an alternative source of energy.

Using local material for building a rural biodigesters can minimize construction costs. The AD technology did not just provide cooking energy but also contributed to the sanitation system (Ogwang et al. 2020). The latest author declares that AD has an important effect on reducing chemical oxygen demand (COD) from FW by about 58%. The authors mention that the process can reduce 99% of pathogens from FW.

11.2.1.1 Fixed Dome

The fixed dome is popularly used in developing countries as a biodigester to recover organic waste and produce biogas and digestate. Figure 11.6 shows the scheme of fixed dome digester and its accessories. It consists of underground digester with inlet for feeding material and two outlets: one for collecting biogas and the second

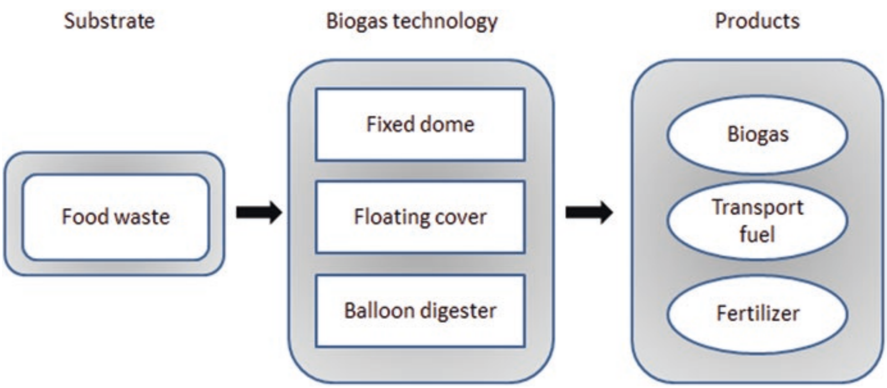

Fig. 11.5 Biogas plant technology for food waste and their products

one for collecting the digestate. In general, the food wastes can be co-digested with cattle manure in a wet fermentation process. Fixed dome digesters provide different positive impact on the environment, but there are limitations in biogas production in winter due to the decrease of temperature which leads to the drop-down of produced biogas volume (Lohani et al. 2021). The main advantages of the fixed dome digester are relatively low cost for construction and a lifespan of more than 10 years. The most disadvantage of the fixed dome digester is that it needs a highly qualified technical constructor to limit the problems of pressure fluctuation. In a research carried out with the design of Chinese Fixed Dome Digesters (CFDD) for the construction of a small-scale digester design that is optimized for rural South Africa, the authors compared a prototype digester with two experimental design features (Ogwang et al. 2020). They found out that the optimized digestion generated 9.3 NL CH_4/KgVS (about 10% more biomethane) than the control digester.

11.2.1.2 Floating Cover

The floating cover digester consists of an above or shallow ground digester made of concrete and steel. The principal design of the floating cover digester is the same as the fixed dome digester. The wastes are fed from the inlet of the digester, and the biogas was collected using a flexible floating cover where the gas is stored (Fig. 11.7). Figure 11.7 shows the scheme of the floating cover digester and its accessories. The most advantage of the floating cover digester is the operation can be visually seen due to the cover which rises and falls with the fluctuation of the gas pressure. The disadvantages of the floating cover digester are the steel utilized in the

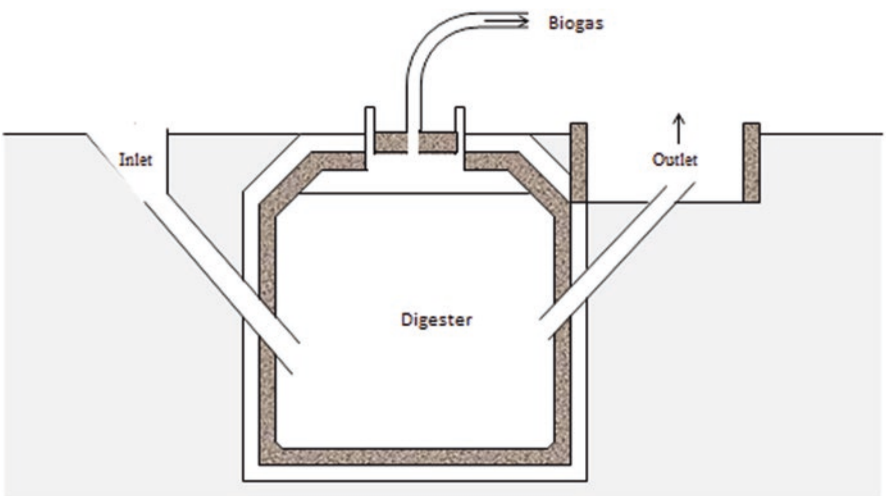

Fig. 11.6 Scheme of fixed dome digester

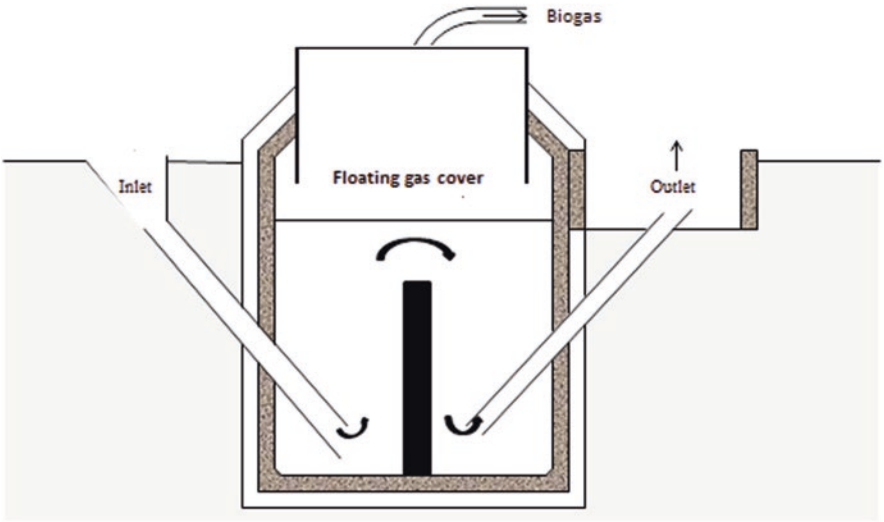

Fig. 11.7 Scheme of floating covers digester

building design is highly expensive; its life duration is relatively limited; and it requires regular maintenance due to corrosion (Orhorhoro et al. 2019).

11.2.1.3 Balloon Biodigester

A balloon biodigester is a plant that combines a digester and a gas holder in a heat-sealed plastic or rubber bag. Figure 11.8 shows the scheme of the balloon biodigester and its accessories. The gas is collected in the balloon's upper section. The inlet and outlet are directly linked to the balloon's skin. Weights can be placed on the balloon to boost gas pressure. The skin may be damaged if the gas pressure surpasses the capacity of the balloon. As a result, safety valves are necessary. A gas pump is required if higher gas pressures are required. Specially stabilized, reinforced plastic or synthetic caoutchoucs are preferred since the material must be weather and UV resistant (Ghiandelli 2017). RMP (red mud plastic), Trevira, and butyl are some of the other materials that have been effectively used. Typically, functional life-span does not exceed 5 years (Zaki et al. 2021). The balloon biogas plants are advised if local maintenance is or can be made possible and the cost advantage is significant.

The advantages of the balloon biodigester include low-cost prefabrication (Kabyanga et al. 2018) and construction sophistication; transportation convenience; shallow installation for use in places where the groundwater table is high; high-temperature digesters are used in hot areas; cleaning without difficulty and sample; and safe maintenance and emptying.

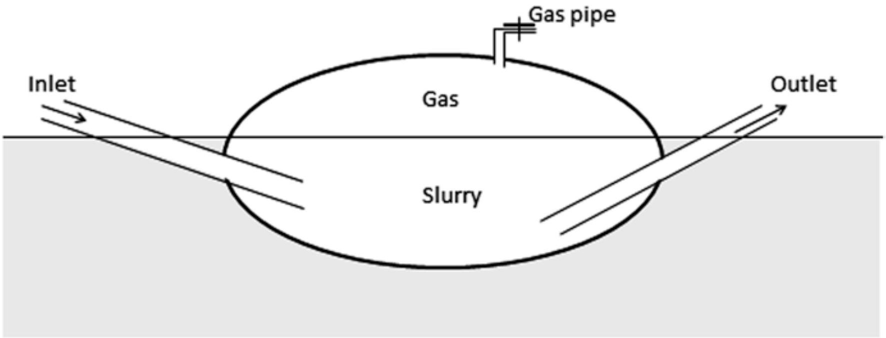

Fig. 11.8 Scheme of balloon digester

The balloon biodigester may necessitate the use of gas pumps for low gas pressure; scum cannot be removed during operation; the plastic balloon has a limited useful life and is subject to mechanical damage; and it is usually not accessible locally. Furthermore, local craftsmen are rarely capable of repairing a broken balloon. There is little opportunity for local employment development and thus low self-help potential.

11.2.2 Rural Biogas and Poverty Reduction in Developing Countries

11.2.2.1 Effect of Biogas on the Developing Countries

Through many biogas applications, biogas technology may contribute to the reduction of poverty in developing countries (Fig. 11.9). Figure 11.9 represents how biogas may be used to reduce poverty. On the one hand, biogas may be used for cooking or heating. Instead of buying wood or charcoal, inhabitants can use it for free in their kitchens. Biogas, on the other hand, may be converted into energy and used to lighting the house or power devices. As a result, citizens would refrain from paying their electrical bills. Some households may go larger distances to obtain hardwoods from a forest or park; but, with biogas technology, they will not have to go as far and also it can help minimizing deforestation. Biogas digesters, according to Shaibur et al. (2021), minimize the time necessary to collect wood for cooking, allowing individuals to pursue education and employment elsewhere. For example, in Nepal, rural household biodigesters can save 2 h/day of time for women and children (Katuwal and Bohara 2009).

Small-scale biogas systems would also help to accomplish the sustainable development goals: SDGs 1: no poverty; SDG 3: good health and well-being; SDG 5: gender equality; SDG 7: affordable and clean energy; SDG 13: climate action; and SDG 15: living on land, according to Lohani et al. (2021). The production of biogas requires working power for the production, collection, and transport of raw

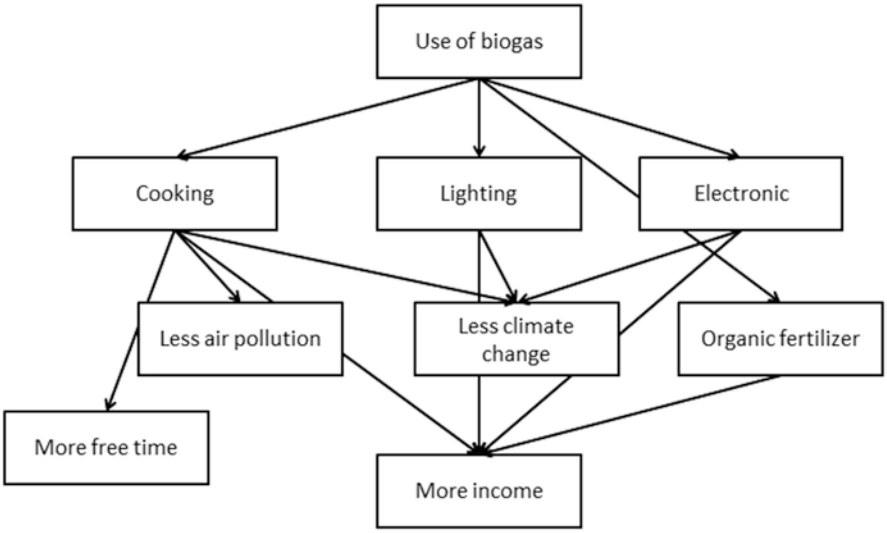

Fig. 11.9 The application of biogas

materials; this implies that the creation of a regional biogas sector helps to generate new jobs. A research shows that, in developing countries, biogas technology can decrease the poverty gap and increase the incomes for biogas adopters more than non-adopters (Rahman et al. 2021). For example, in Bangladesh, biogas adopters had a household poverty gap of around 16% smaller than non-adopters. The authors declare that biogas adopters have a per capita household income between 13% and 27% more than non-adopters. A study showed that a 10 m^3 fixed dome digester can produce up to 2.5 m^3 per day of biogas, which is equivalent to 13 kg of firewood (Diouf and Miezan 2019). In a recent study, we find that five families (each with eight individuals) have constructed a fixed dome digester utilizing co-digested cassava and vegetable and fruit waste in the design of a household biogas digester (Sawyerr et al. 2020). With a mass of incoming biomass of 465.12 kg/day, the installed digester generates 10 m^3 biogas/day. The digester's material cost is estimated to be at R 121 136.09 (South African Rands) by the authors (which is equivalent to 7 792.75 USD) .

The production of the rural population, which lives below the national poverty line, is mainly dependent on traditional biomass fuels such as wood and dung cake (dried cattle manure) (Rahman et al. 2019). The biogas digester for domestic use can contribute to achieving the UN Millennium Development Goal (MDG). Among these MDG, we can (i) cite reduction in poverty and hunger (MDG 1), (ii) empower women and maintain gender equality (MDG 3), and (iii) ensure environmental sustainability (MDG 7) (Amigun and von Blottnitz 2010). As domestic biodigesters increase employment, they can also enhance the quality of living. The domestic biodigester improves the sanitary facilities that can eradicate different diseases and cause annual numbers of deaths.

11.2.2.2 Recommendations to Promote Biogas Technology in Developing Countries

Various significant government engagements are necessary to understand what caused domestic biogas plants to operate successfully or unsuccessfully and to investigate potential obstacles (Bond and Templeton 2011). Biogas stoves look to have fresh development potential in light of the current push to minimize indoor air pollution by promoting cleaner cookstoves. According to the authors, low-cost designs with greater resilience, functionality, and simplicity of building, operation, and maintenance would help biogas plants gain market share. Furthermore, small-scale bioreactors that successfully digest accessible substrates in both rural and urban settings are required to move beyond a reliance on animal dung.

In a study carried out to bring attention to the state of energy usage in developing nations, they have mentioned the role that AD for biogas generation may and does play in satisfying these countries' energy and waste management demands (Surendra et al. 2014). The author states that developing countries have a big challenge in terms of the construction of biogas digesters and its maintenance costs. The authors recommend that construction costs must be reduced and that the direct and indirect costs and advantages of biogas technology should be evaluated and assessed. Provisions for financial services (soft loans) should be made accessible, according to the authors, to increase rural communities' access to biogas technology. Microfinance institutions set up in selected regions might be one option to consider so that impoverished people have simple access to a range of financial services. The authors give an example in Nepal; over 260 microfinance organizations provide financing to households that cannot afford the upfront cost of a biogas system.

Government agencies and non-governmental organizations (NGOs) might play an important role in encouraging digester owners to install new efficient digester technology, optimize critical operational parameters, and better manage digesters and locally accessible feedstocks (Khan and Martin 2016). The authors indicate that

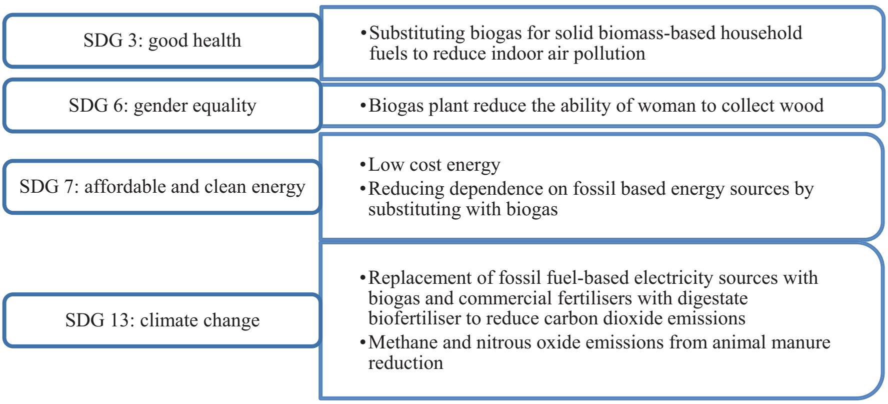

Fig. 11.10 Biogas plant contribution to achieve sustainable development goals

it is critical to make a gradual adjustment in attitudes and policies in order to replace the chemical fertilizer assistance program. According to the authors, in rural Bangladesh, biogas competes primarily with (free) solid biomass financial investments, and the biogas may fail to break even over time. Developing a sustainable biogas energy system in rural regions necessitates extensive changes in all techno-economic, social, and policy elements and is one of the most important investments in the future Fig. 11.9. .

11.3 Main Obstacles to Overcome for Biogas Technology Promotion

In order to promote biogas technology in a given country or region, it would be necessary to be aware of the main obstacles that hinder the development of biogas as a renewable energy source. It is important to know what are the largest obstacles the region/country needs to overcome so that the biogas industry can reach its full potential. In general, six types of obstacles and barriers can be found in the literature: (i) institutional, (ii) technical, (iii) economic, (iv) market, (v) environmental, and (vi) sociocultural (Nevzorova and Kutcherov 2019). These authors compare these barriers in developed and developing countries.

The promotion of biogas technology may be based on a country's geographical data, development level, and weather; thus, it is critical for each country's biogas strategy to determine its particular obstacles.

In this paragraph, we will first give a bibliographical review on these different obstacles that hinder the development of the biogas sector in developing countries. In particular, we will indicate, according to this bibliographical study, the priority ranking according to different authors and countries. Then, the priority order for each of the six types of barriers according to different authors and studies will be determined. In this context, different methodologies were used to realize these research studies. In a recent study, the analysis of the financial, technical, social-cultural, and institutional impediments to biogas transmission, in sub-Saharan Africa, was done (Rupf et al. 2015).

In other research, the authors summarize the primary barriers to adoption found during stakeholder interviews, as well as suggestions for how to overcome each of them, based on the lessons gained (Mukeshimana et al. 2021; Budiman 2021).

Biogas diffusion obstacles in India were identified using composition analysis. Financial, information, market, social, and cultural hurdles, as well as regulatory and institutional, technological, and infrastructural barriers, were all cited as major roadblocks (Mittal et al. 2018). The authors compared these hurdles in India's rural and urban areas. This suggests that biogas penetration barriers vary depending on the use area, substrate, resource potential, technological maturity, and scale. These variables may differ by country or region.

In Africa, biogas generation stands out as a viable solution with various advantages, particularly in terms of reducing health risks, indoor air pollution, and deforestation, which is rapidly becoming a severe issue in the country. However, the majority of biogas production initiatives have failed because more than 40% of the population lives in rural areas where firewood is the primary source of heat, cooking, and other necessities (Dahunsi et al. 2020).

In a recent study, the importance of the obstacles was ranked using the Analytical Hierarchy Process (AHP). This research revealed that financial barriers are the most powerful, with high capital costs and a lack of finance mechanisms ranking high among all hurdles (Mukeshimana et al. 2021).

The priority ranking of the four categories of barriers is shown in Fig. 11.10. Fig. 11.11. Financial constraints were placed first, followed by institutional impediments, with technical and sociocultural barriers ranking third and fourth, respectively.

In another study, the purpose was to determine systemic obstacles to biodigester adoption by looking at the landscape of biogas governance in Indonesia, its fragmentation, and its relevance for biodigester adoption (Budiman 2021). This research reveals impediments to technology adoption that go beyond the user/individual level. It depicts the interaction of various aspects such as policy, technology transfer governance, technical production concerns, and sociocultural issues.

11.3.1 Financial and Economic Barriers

In developing countries, high capital costs combined with widespread poverty are major economic barriers. Biogas systems are unique in that almost all costs are incurred up front, while operational costs are minimal.

In Africa, biodigesters' high initial costs are a significant obstacle to implementation. Increased access to finance is one strategy now being used to address the high initial investment costs (Meyer et al. 2021).

In fact, the initial costs of building a biogas plant, such as construction, labor, and equipment, are relatively high for rural households. The entire cost of installing a family biogas plant varies depending on the size, location, and model.

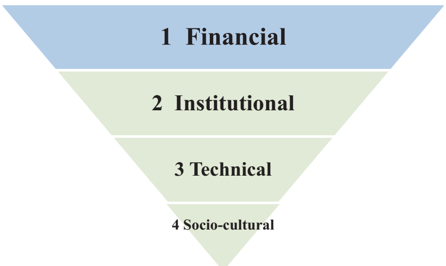

Fig. 11.11 The priority ranking of the four categories of barriers. (Adapted from Mukeshimana et al. 2021)

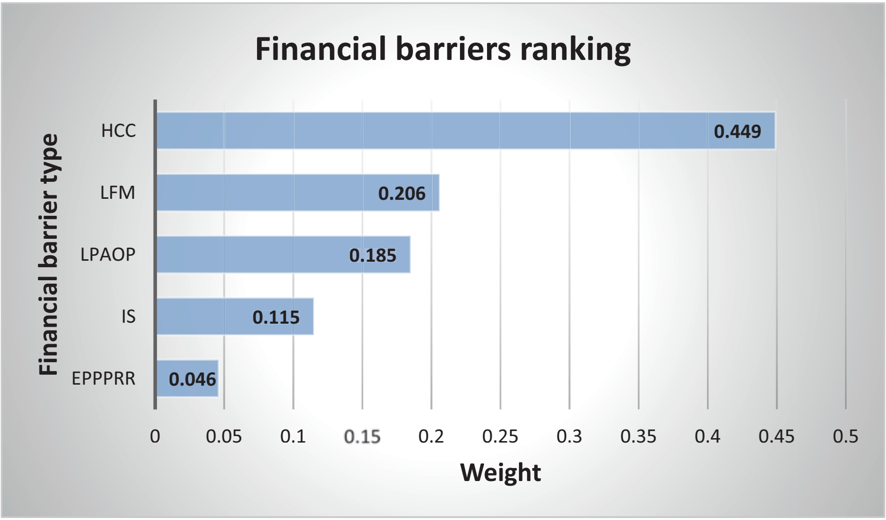

Fig. 11.12 Financial barriers ranking. (Adapted from Mukeshimana et al. 2021)

As shown in Fig. 11.12, *high capital costs (HCC)* were the most highly regarded financial barrier, followed by a *lack of financial mechanisms (LFM)*. Meanwhile, *lack of paying ability owing to poverty (LPAOP)* and *insufficient subsidies* (IS) were rated third and fourth, respectively, while the *extended payback period and poor rates of return (EPPPRR)* were ranked last. The expense of technology installation was noted by many stakeholders as a problem in biogas generation (Budiman 2021).

11.3.2 Institutional Barriers

According to literature assessment, government intervention is still necessary. In many cases, political support and particular programs to promote biogas technology are lacking. The National Biogas and Manure Management Program, launched by the Indian federal government, takes a top-down strategy. The program is inefficiently targeted because owning 2–3 cattle is one of the criteria for receiving capital subsidies to establish a biogas plant under the program (Mittal et al. 2018).

The most significant policy barrier to biogas adoption in Bangladesh was found to be a "no feed-in tariff policy." "Lack of concrete biogas policy" and "Insufficient attention from government" were the other major policy hurdles, followed by "Lack of financial policy" (Hasan et al. 2022). The governance problem inside biogas projects has an impact on production and consumption barriers (Budiman 2021).

11.3.3 Technical Barriers

The lack of locally sourced biogas technologies can make it difficult to deploy biogas as a source of energy. Biogas plant production is influenced by operator expertise, professional employees, and well-trained workers (Nevzorova and Kutcherov 2019). Poor design and lack of standards for biogas construction, insufficient feedstock supply, and a lack of technical services and research and development facilities are all examples of technical barriers (Mukeshimana et al. 2021). The results show that "lack of waste treatment and storage facilities," "lack of feedstock supply," and "planning and installation challenges" were the most significant technical barriers to biogas technology deployment (Hasan et al. 2022).

11.3.4 Sociocultural Barriers

Biogas adoption in rural areas is hampered by a number of social and cultural hurdles. First, due to the associated social shame, people and plant owners are hesitant to employ night soil/human excreta in biogas plants (personal communication E). Second, in rural households, women are generally responsible for cooking and are thus exposed to indoor air pollution induced by solid fuel combustion (Mittal et al. 2018). Most of the social obstacles can be overcome by taking social and cultural considerations into account when designing systems, as well as properly communicating with potential biogas users about the suitable use and benefits of biogas technology to fulfil their needs (Rupf et al. 2015).

The consumption barrier is linked to community social difficulties. People's socioeconomic acceptance of biodigesters also contributed to low demand (Budiman 2021).

11.3.5 Market Barriers

Lower fossil fuel prices and a higher price for biogas are major market hurdles. Biogas is more expensive than natural gas, which worries users because they will pay more than "normal." In order for biogas to reach the public sector, its price must be competitive with other available fuels (Nevzorova and Kutcherov 2019). Another difficulty in obtaining organic biomass feedstock in villages is the lack of local markets for these feedstocks (Mittal et al. 2018). Since conversion losses are minimized with biomethane injection into the natural gas grid, it is an effective delivery system.

In Bangladesh, the most significant market hurdle to biogas deployment was described as an "immature biogas market." "Lack of involvement in the global carbon market" and "unsettled energy market" are two additional important impediments mentioned. In the Bangladesh biogas market, "low primary-end-user demand" and "competition with fossil fuels" are deemed less important (Hasan et al. 2022).

11.3.6 Environmental Barriers

Despite the fact that biogas has a number of important environmental benefits, few authors address potential negative factors such as noise pollution, odor complaints, and the necessity for ample water supplies for biogas digesters (Nevzorova and Kutcherov 2019). AD necessitates a large volume of water, with a ration of water and manure to be placed into the digester of 1:1 (Kelebe 2018). As a result, while biogas generation may not be a problem during the rainy seasons, but it may be a problem during the dry seasons, particularly where the distance to water supply is great and in areas where water is scarce (Kelebe 2018).

Soil biodiversity, water storage and retention capacity, erosion management, and agricultural yield stability are all directly connected to soil organic matter concentration (Pirelli et al. 2021). As a result, the author mentions that monitoring and evaluating soil organic carbon (SOC) as an indicator for soil quality is critical for determining the long-term viability of bioenergy crops and defining appropriate management techniques.

11.4 Conclusion

Several biomass conversion technologies are used to valorize organic wastes. These technologies cover a wide range of biological/biochemical processes that produce biofuels and value-added goods, among other things. The promotion of biofuels, particularly bioethanol, in the industrial or agro-industrial sector has led to a rise in the need for process quality certificates, which attest to the efficacy of alternative energy sources. The largest issues with producing biofuel in developing nations, however, go beyond the negative effects of using subpar technology or ignoring its growth. The industrial sector has to support and put in place innovative methods, devices, and infrastructure for boosting bioethanol production effectively while juggling societal and environmental demands. Government funding and extensive research are needed to promote the best expansion of the biofuel industry. Tax concessions and financial aid for biofuel companies must be used to promote the growth of bioethanol.

Note that assessing the sustainability of first-generation bioethanol is not an easy task, as it depends on several factors related to the economic situation of the country in terms of food security and agricultural activities.

Poor management of significant amounts of organic waste has the potential to harm the ecosystem and cause major problems. AD is used to treat these wastes and can produce biogas and digestate. Fixed dome, floating cover, and balloon digesters are the most popular digesters used in developing countries. Through various biogas applications, such as cooking or heating, as well as energy for lighting the house or the usage of electronics, biogas technology may aid in the reduction of poverty in developing countries.

In recent years, there has been a lot of interest in the existing obstacles to the widespread use of biogas as an energy source. Thus, awareness of the hurdles to wider adoption of biogas is important to handle, as well as their potential impact on the energy industry as a whole. The general barriers can be defined as six interrelated sets of constraints in both established and emerging economies. These barriers are technical, economic, market, institutional, sociocultural, and environmental. High capital costs and widespread poverty are significant economic obstacles in developing countries. Political support and targeted initiatives to advance biogas technology are frequently absent. Biogas production is influenced by skilled operators, qualified staff, and trained employees. People and plant owners are hesitant to use night soil or human excreta in biogas plants, which influences biogas adoption. Because biogas is more expensive than natural gas, users are concerned that they will end up paying more than necessary. Even though biogas has a number of significant environmental advantages, there are different inconvenient factors, such as odor complaints, noise pollution, and the need for sufficient water supply for biogas digesters.

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