Chapter 10
Impact of Bioenergy on Environmental Sustainability

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Abstract Energy and environments are vital elements to our daily life and a way forward for our viable development. The fossil fuels are widely used as primary energy sources that threaten its depletion along with the formation of various harmful greenhouse gases. This necessitates for efficient utilization of energy and the access to the alternative energy resources like bioenergy. It is always being a major concerned for bioenergy deployment while referring to availability of the biomass, competition between the various uses of biomass and the sustainability issues. In spite of its wide applications, there is less study on the environmental effects of bioenergy. This enthuse the challenges that calls for multidisciplinary researches related to environmental sustainability. Production of bioenergy conveys significant prospects to provide a series of environmental, social, economic benefits in addition to the energy and climate goals. In order to open up better chances for agricultural souk and to endorse sustainable growth in rural community, bioenergy plays a vital role. Proper planning and management might yield multiple benefits using bioenergy synergies with the production of food, water, ecosystems and health. This chapter addresses a survey on pertinent literature related to the environmental sustainability arising from the production of bioenergy. In this context, the chapter also deals with the bioconversion technologies and its impact on environment and applications, greenhouse gases and biodiversity, etc.

Keywords Bioenergy · Bioenergy production · Environmental sustainability · Economic benefits

10.1 Introduction

Bioenergy as a main source of renewable energy plays a vital role in the modern energy systems. It is always been a concern about the availability of biomass, contest

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R. Praveen Kumar et al. (eds.), *Biomass Valorization to Bioenergy*, Energy, Environment, and Sustainability,
https://doi.org/10.1007/978-981-15-0410-5_10

between the various biomass uses, as well as the sustainability anxiety to the bioenergy growth. Regardless of immense qualms, the majority approximations indicate that biomass is likely to be adequate to play a important role in the comprehensive energy delivery system. Severe use of carbon based fossil energy results various environmental impact that have made many nations to start short, medium and long term plans aiming to efficient employment of renewable energy. Bioenergy may be considered as the enormous source of the renewable energy which may contribute to the half of the world's total renewables consumption, i.e., as much as hydro, wind, solar and all other renewables combined (International Energy Agency 2018). Bioenergy can have a certain influence on decarbonizing some sectors like cargo road transport, aviation, nautical transport, etc. Growth of bioenergy depends on the ability to accumulate huge amount of biomass. The direct and indirect trade of biomass might play a leading role in the bioenergy development in near future.

Biomass includes a broad range of feedstock from different parts like lignocellulosic biomass, agricultural food biomass, waste of biomass which includes several conversion ways: biochemical, chemical, thermochemical, etc. These conversion processes generally rely on the nature of the accessibility of biomass and the energy needs. Therefore, the resultant efficiency of the energy not only depends on the resources of biomass, but on the technology also which is engaged for the energy conversion.

In order to ensure a competitive, sustainable, and safe energy, supportive policies are always needed to obtain the energy and climate targets. The latest developments in renewables and technology help in reduction of the investment costs (mostly for solar photovoltaic and wind energy). It is interestingly noted that availability of relatively cheap or even negative cost of feedstock makes bioenergy study competitive in several cases.

Support requires are usually modified on the basis of the feedstock, technology and volume of the plant. An appropriate policy structure and stronger implementation procedures are required to prop up the bioenergy production, to benefit the energy system of low-carbon and to achieve the targets for reduction in emissions. Considering certain specific circumstances to gain growth in a balanced market, support should be distinguished among technologies, feedstock, and plant size at different level of development.

The bio-based economy is dependent on the sustainability of biomass. Studies revealed that use of biomass lowers greenhouse gases emissions in comparison to the use of fossil fuel if change in land use can be prevented. Biomass production, using low energy input or highly efficient residue streams or renewable energy, emits lower greenhouse gases as much as close to carbon neutrality. The noteworthy opportunities of biomass production include social, environmental and economic profits along with climate and energy goals. It also helps agricultural markets and helps in promoting stable development in rural communities. Bioenergy combined with the production of food, ecosystem, water, health and welfare might provide numerous benefits on proper planning and management.

The future role of bioenergy is highly challenged in European countries where use of clean energy is of utmost motive. The composition of advanced biofuels must be similar to drop-in biofuels to prevent the costs of new power train infrastructures. The future research of biomass will comprise of improvement of net process efficiency of biomass conversion and to develop cost-effective technologies for production of new biofuels.

Biomass is considered as a renewable resource but its use is limited due to the finite resources those necessary for production. Because of the rising interest on bio-economy, the biological assets are sustainably formed and transformed into final value added products. This chapter encompasses the basis of bioenergy/biomass production and the composition/characterization resulting from their productions that decide the different biomass types and classification. Moreover, a wide review of the various biological resources at global scale centering on their various environmental impacts is reported.

10.2 Overview of Bioenergy Research

Practically for the betterment of a society in the world it requires energy to be the basic condition for development and this is also vital for the existence of ecosystems along with the life and human civilizations (Jiang et al. 2014; Ozturk et al. 2017). Nevertheless, the utilization of conventional energy sources can raise various problems like the conventional energy resources like fossil fuels are not renewable, and its overuse will lead to major catastrophe of energy and thus becomes a big worry for the world. Another problem may be the environmental pollution because of the utilization of the traditional fossil fuels which accelerates the global warming, for example, increases of carbon dioxide and other greenhouse gases (Mallick et al. 2017, 2018). Again, it may be noted that the released nitrogen oxides due to the combustion of the fossil fuel compromise the quality of air and causes harms to the health of human beings (Hoekman et al. 2018). It is very much unfortunate that the consumption of energy highly depends on the fossil fuels and will increase in the coming years (Ozturk et al. 2017). Therefore, bioenergy may be considered as the strong renewable substitution of fossil fuels to achieve the safeguard of the energy security, mitigate the global warming and the rapid growth of the world population (Hoekman et al. 2018). Recent studies (Sang and Zhu 2011; Wu et al. 2015) unveil the fact of using different feedstocks for biofuel production. Thus, bioenergy draws attention to a great extent and engaged an active status in the energy consumption of earth with reference to the change of climate (Jiang et al. 2012). According to the world energy council and the report (Souza et al. 2017), 14% of global energy consumption is accounted by the bioenergy. However, it is expected that there might be an admirable potential of bioenergy in future. In the developing countries sustainable production of bioenergy can proficiently diminish the peril of energy poverty and subsidize to the economic growth (Schroder et al. 2018; Wicke et al. 2011).

Therefore, a government around the globe tries to promote the production of bioenergy and looking for suitable policies or regulations for its development. For example, EISA (The Energy Independence and Security Act, US Congress 2007) is instigated by the government of the United States to upsurge the accessibility of renewable energy through the production of biofuels. Similarly the eighth Malaysia plan (2001–2005, the fifth fuel policy) is fortified to promote the production of bioenergy (Tock et al. 2010). In the recent time, China shows genuine demand for the production of bioenergy in conjunction with the rapidly emergent economy that prevents the energy disaster, and achieving the goal of reduced emissions of greenhouse gases. In reality, it has possible bioenergy crop farming due to its better profit and ecological benefits. It may be noted that the extension of bioenergy raw material production might potentially cause some adverse ecological modifications yet it is considered to be an influential source for energy safety. Now-a-days, scientists from all over the world have paid enormous attention to the balance between the production of bioenergy and safeguard of the environment. This can be done by choosing multiple approaches, including the best management practices (BMPs) (Guo et al. 2018; McCalmont et al. 2017; Wu and Liu 2012). However, involvement of the complexity in the bioenergy production system and the deficit information make the knowledge of the overall environmental effects unclear. Therefore, an overview of the present situation regarding the production of bioenergy and its impacts on environment is required. Following the article (Wu et al. 2018) it has been observed that bioenergy production and its environmental effects were examined within the reference period of 17 years starting from the year 2000–2017. The research work relevant to bioenergy is observed to grow continuously from the year 2000. However, the pertinent studies of bioenergy involving environmental effects (e.g., water quality and quantity, Greenhouse Gas emissions, biodiversity and soil erosion, etc.) increased gradually with a diminutive growth rate since 2000. Furthermore, the continuous boom of publications associated to environmental impacts suggests that more and more attention is paid to the protection of environment while endorsing the development of bioenergy.

10.3 Production of Bioenergy/Biomass

Bioenergy may be the renewable energy that is obtainable from material derivative of biological sources. Biomass is kind of organic material which is capable of storing the sunlight in the form of chemical energy. The resources needed in the production of bioenergy are termed as feedstock. In order to know better of biomass, it is important to explore the several sources first. The production of biomass is based on the increase in the quantity of organic matter in a specified area. Biomass is chosen as the renewable energy because it is stocked up as animals and plants grow. There are generally two different ways of production: (i) primary and (ii) secondary production. Primary production is related to the production of energy by the plants in the course of photosynthesis. The gross amount of biomass in the environment is increased by storing and adding the extra energy generated. In this production system, production might be assessed from the total cover of the forest in a particular year. The other type of production i.e. secondary type involves assimilation of the organic substances as body tissues used by different organisms. In this production, animal's feeding on other animals or plants and decaying of the organic matters through micro level organism is involved. It might be also estimated based on the total meat production per year. Although biomass might be evaluated as much as organisms living and dead in a given circumstances, it is difficult to guesstimate the production. This may be reviewed as the raise in volume though part of the supplementary biomass may have been substituted through natural processes. Various methods of producing bioenergy are discussed next.

10.3.1 Direct Combustion (For Heat)

From the earliest civilizations, it has been noticed that biomass conversion to energy through direct combustion is the oldest procedure exist in the present scenario. By varying feedstock in different ways, thermochemical conversion could be attained. The various ways of direct combustion are detailed as follows:

10.3.1.1 Standalone Combustion

The bio mass generators usually burn the organic fuel in order to produce electricity. There are varieties of ways to complete the combustion process by means of different feedstock, application range and the conversion ways.

(a) Bio-mass generators: Vegetable oils (for e.g., jatropha, nahar etc.), may be capable of replacing diesel in diesel generators to generate electricity suitable for off-grid applications or self-regulating mini-grids.
(b) Bio-mass power plants: The heat resulting from the direct combustion of biomass in a boiler might be utilized for producing electricity using a steam turbine or engine. Though the efficiency related to the electricity generation of the steam engines is not high enough as expected but it is presently the cheapest and most trustable way to generate power from biomass in standalone type of applications (IEA 2009).
(c) Biomass-based co-generation plants: The process of co-generation is used for producing two valuable forms of energy from the same fuel source, i.e., electricity and heat. The overall efficiency of a power plant may be significantly increases because of the co-generation which also results in competitiveness provided there may be an economic application for its waste heat (IEA 2009). The overall efficiencies of a combined heat and power (CHP) plants may be in a range from 80 to 90%. Some industries like, pulp and paper, palm oil mills, sugar mills use the heat from the biomass combustion.
(d) Municipal solid waste (MSW): Waste-to-energy plants is a very much different and heavily tainted feedstock, necessitates strong technologies, rigorous emission control systems, leading to the increase of the costs of waste-to-energy amenities, makes MSW a largely idle energy resource despite its noteworthy potential in many countries (IEA 2009).

10.3.1.2 Biomass Co-combustion

In addition to the stand-alone combustion, biomass might be combined with other fossil fuels and burnt to generate energy. Biomass co-combustion (or co-firing) includes adding of existing fossil-based (mostly crushed coal) power plants with biomass feedstock (IEA 2009). Woody to grassy and straw-derived materials which include both residues and energy crops are considered as biomass fuels. Based on the different types of biomass, the properties of biomass change significantly and also differ from those of coal. The properties of the biomass having lower heating value and low bulk density might differ from those of coal having higher values of ash, moisture and chlorine content. The performance of co-firing/co-combustion systems highly depends on these properties (IEA Bioenergy, Task 32 2002). There are three basic types of biomass co-firing available and those are as follows:

(a) Direct co-combustion: Existing coal furnace is used to burn the biomass directly. This type of co-combustion maybe done either by pre-mixed the raw solid biomass (granular and dust form), with the coal in the coal handling system or by injecting directly to the crushed coal firing system.
(b) Indirect co-combustion: The resulting synthesis gas is burned in the coal furnace after the biomass gasification.
(c) Parallel co-combustion: With the steam produced within the main coal power station steam circuits are used to burn the biomass in separate boilers (IEA 2009). Indirect and parallel co-combustion options are considered to avoid biomass-related contamination problems. Parallel or indirect co-combustion are much more expensive than the direct co-firing approach as latter requires additional infrastructure. One of the applications of parallel co-combustion units are pulp and paper industrial power plants (IEA 2009).

One of the main advantages of biomass co-combustion is that it may reduce the greenhouse gas (GHG) emissions from the coal fired plants and enables effective power generation with a higher efficiency. The efficiency can be increased further if the co-combustion takes place in the combined heat and power (CHP) plants. The cost factor is also an advantage of biomass co-combustion as the rising investment for burning biomass in coal-fired plants is significantly lower than the cost of dedicated biomass power. In the present scenario, co-combustion projects in coal-fired plants are more than the biomass capacity of the biomass plants. Kijo-Kleczkowska et al. (2016) studied the processes and kinetics of combustion of sewage sludge, coal and biomass and their co-combustion in pellets having spherical shapes. The adding of sewage sludge to hard coal and lignite reduces combustion periods when matched with coal, and the adding of sewage sludge to willow *Salix viminalis* yields an increase in combustion period. Guo and Zhong (2018) studied the simultaneous combustion of biomass pellets and coal by means of thermo gravimetric analyzer and fluidized bed. The pellets mixing ratio of 30% is thought to have optimal ratio for coal and biomass pellets, accordingly having minimum activation energy and slagging problem. The addition of biomass pellets can lessen the production of polycyclic aromatic hydrocarbons (PAHs) and trace metals. Khanmohammadi et al. (2019)

developed a novel thermodynamic model to extract excess heat using thermoelectric waste heat recovery systems (WHRSs) in integration with biomass power generation. The investigation showed that the first law efficiency of the system was increased by 0.35% if all the heat coming out from the stack passed through the WHRSs. Whereas, on placing the WHRSs in such a way that the entire heat from the condenser passed through it, the first law efficiency was increased by 1.17%.

10.3.1.3 Types of Combustion Systems

As discussed in the previous sections, combustion/burning are the oldest and conventional procedures to obtain high temperature from the biomass. The high temperature is obtained by converting the chemical energy contained in biomass through numerous chemical reactions during biomass burning. The good reaction between the oxygen in air and the biomass might influence the efficiency of the combustion. The major products result inefficient combustion of biomass are CO_2 and H_2O vapor along with secondary production of smoke, tar, alkaline ash particles, etc. The classification of various types of combustion systems is shown in Fig. 10.1. Fixed bed and fluidized bed combustions, suspension burners, etc. are the most common type of combustion systems available in biomass based power plants.

When the solid biomass is first cut into small pieces and then burnt on a flat static surface, it is known as fixed bed combustion. The rise in temperature in fixed bed systems are in a range from 900 to 1400 °C. The combustion of biomass fuels with higher moisture and ash content takes place in grate furnaces. The grate system helps in providing uniform distribution of fuel and bed. Fixed grate systems are suitable for small scale applications. Managing the fuel transportation in such systems is

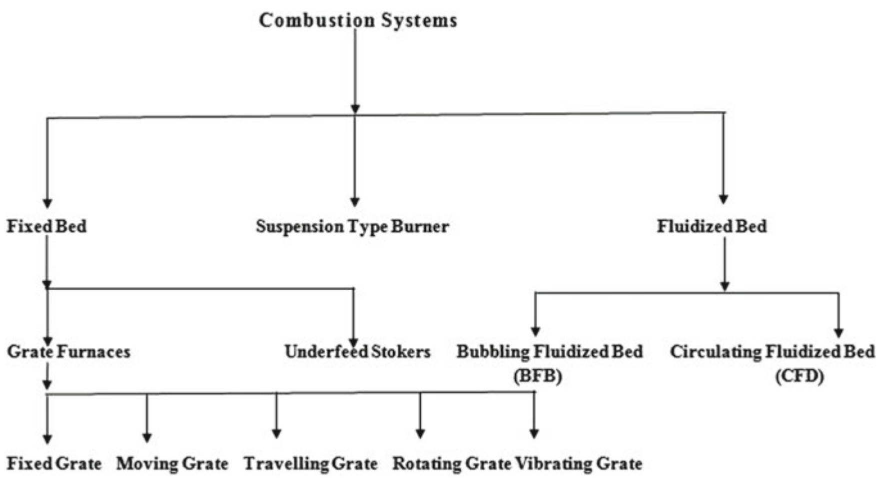

Fig. 10.1 Classification of combustion systems

generally based on consuming of fuel and the gravity action produced due to the inclination of the grate. In moving bed combustion, a grate is set to constantly and evenly move leaving ash behind. The fuel burns in combustion levels. They may be inclined or horizontal in design. In case of travelling grate systems; the grate bars form an endless band through the combustion chamber. When biomass fuels having small amount of ash and tiny particles, underfeed stoker fixed bed combustion systems are more appropriate. These are flexible in case of the load changing behavior. In case of dry biomass (<15% moisture) with very fine particles, suspension burners are suitable. These types of burners are having higher specific capacity. It produces the flame very similar to oil fired burner. It is found that suspension burners are not up to the level whenever efficiency is concerned. This is attributed to the excess air needed to prevent the formation of slag in the combustion system and there is an enormous production of fly ash. Again when fuel is boiled under high pressure mixed with sand, the sand serves to distribute the heat evenly. This is known as fluid bed combustion. This type of combustor comprises of a cylinder attached to a perforated base plate filled with a suspension bed of granular materials. Dolomite, silica, and sand are the common materials for bed. Air is blown through the perforated bottom plate to fluidize the bed using a fan. It aids in rapid transmission of heat generating a large heat transfer surface. These combustors can handle easily different sizes and shapes of fuel particles, high moisture and ash content. Lee et al. (2019) analyzed the economic viability of a 600 MW ultra-supercritical (USC) circulating fluidized bed (CFB) boiler functioned with coal or a combination of coal and biomass as fuel. The economic viability was assessed in terms of collective cash flow, payback period, NPV, and IRR. In spite of high capital costs, low technology and high power use, the USC CFBC was highly developed to achieve clean environment and high energy conversion efficiency. In burner combustion, wood dust and fine dust are placed in a burner similar to that of liquid fuel. When a kiln furnace is used to burn organic matter with high moisture content, such waste as food residue or other moist farm waste is burnt this way is known as rotary furnace combustion.

10.3.2 Thermochemical Methods of Biomass Production

10.3.2.1 Pyrolysis

Pyrolysis is another form of processing bio-fuels by burning under very high temperatures without oxygen, which might cause complete combustion. This is responsible for the irreversible physical and chemical variations. In the absence of oxidation and halogenation processes, it may result a very dense bio-fuel that could be used in combustion, co-combustion or changed to gas. The solid charcoal can be obtained through slow pyrolysis at about 400 °C. Fast pyrolysis occurs in a temperature range from 450 to 600 °C and it results in various organic gas, pyrolysis vapour and charcoal. The vapour is then condenses to liquid form as bio-oil. This conversion must be done within fraction of seconds to prevent further reaction. The liquid obtained through this process is dark brown and it is denser than wood biomass and has equal content in energy. The bio-oil is easier to transport, burn, and store. Several kinds of feedstock can be processed through pyrolysis to produce biooil. Figure 10.2 describes the conversion of energy into a usable form of bio-fuels through pyrolysis.

The main advantage of pyrolysis being an attractive option to attain bioenergy is due to its carbon negative property (Glaser et al. 2009; Lehmann 2007), increased biogas, biooil and biochar production (Zhang et al. 2010; Aysu and Küçük 2014). Following the report (Manara and Zabaniotou 2013), the pyrolysis process might be classified into four stages, i.e., (i) moisture evolution, (ii) hemicelluloses decomposition, (iii) cellulose decomposition and (iv) lignin decomposition. The chemical bonds usually break and form a new compound in the absence of oxygen. The organic matters present are converted into (i) gaseous (or major components are CO_2, H_2, and CO, syngas), (ii) liquid (i.e., biooil) and (iii) solid (biochar) fractions that are used for generation of electricity (Zabaniotou 2014; Akhtar and Amin 2012). It is reported in the articles (Xiu and Shahbazi 2012; Lehmann et al. 2006) that bio oil is having the potential of being applied as biofuels (renewable) for combined power stations or in generation of power and in a transport systems. The net reduction of CO_2 emissions could be achieved while biochar blending has been applied with the fertilizers in the cropland (Chan et al. 2007; Lehmann et al. 2003). There are generally three main categories of pyrolysis as shown in the Table 10.1 (Patwardhan 2010; Goyal et al. 2008). Detail study of these processes is discussed in (Ben and Ragauskas 2013; Lee et al. 2013; Kan et al. 2016).

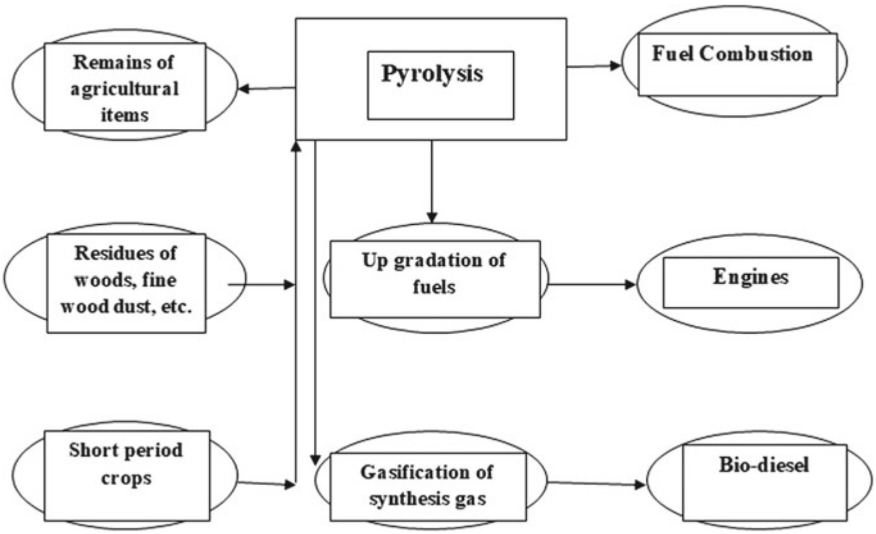

Fig. 10.2 Conversion of energy through pyrolysis

Table 10.1 Types of pyrolysis, related operating conditions and the final listing of products (Patwardhan 2010; Goyal et al. 2008)

Types of pyrolysis	Operating conditions			Final products		
	Operating temperature	Rate of heating	Retention time	Char	Bio-oil	Syngas
Slow pyrolysis	400–600 °C	5–7 °C/min	5–30 min	Lesser than 35%	Lesser than 30%	Lesser than 40%
Fast pyrolysis	400–600 °C	300 °C/min	Lesser than 5 s	Lesser than 25%	Lesser than 75%	Lesser than 20%
Flash pyrolysis	400–600 °C	1000 °C/s	30 ms–1.5 s	Lesser than 25%	Lesser than 70%	Lesser than 16%

10.3.2.2 Biomass Gasification

Biomass gasification or thermal gasification is the method of transforming solid fuel into the gaseous fuel through thermo-chemical means without leaving any carbon contain solid residue. This technology is now an established technology and its application of commercial use has been found since 1830. The equipment that transforms biomass into producer gas is known as gasifier. Gasification involves partial combustion and reduction operations of biomass. Partial combustion indicates oxidation in limited quantity of air or oxidant. In a classic combustion process usually there is an excess of oxygen, while in gasification fuel is in excess amount. The combustion products, mainly CO_2, water vapour, N, CO and H pass through the shining layer of charcoal to ensure the reduction process. In this stage both CO_2 and water vapour, oxidize the char to form carbon monoxide, hydrogen and methane. Major reactions involved during gasification are as follows (Khan 2017):

$$C + O_2 \rightarrow CO_2 \quad \text{(Combustion, 240 kJ/mole)}$$

The available moisture in the biomass is transformed into steam and generally there is not any requirement for extra moisture. Thus the product of combustion pyrolysis gases results in CO_2 and steam (H_2O), which later reacts with the char:

$$C + CO_2 \rightarrow 2CO \quad \text{(Boudouard reaction, } -164.9 \text{ kJ/mole)}$$
$$C + H_2O \rightarrow CO + H_2 \quad \text{(Water gas reaction, } -122.6 \text{ kJ/mole)}$$
$$CO + H_2O \rightarrow CO_2 + H_2 \quad \text{(Water shift reaction, 40.2 kJ/mole)}$$
$$C + 2H_2 \rightarrow CH_4 \quad \text{(Methane reaction, 83.3 kJ/mole)}$$

The degree of equilibrium attained among various reactions decides the composition of the gas produced. Gasification may be regarded as a suitable process for obtaining eco-friendly energy. In this process material is burnt in a temperature range from 800 to 1300 °C (Panwar et al. 2012). The syngas produced during gasification can be used for the energy generation by means of turbines or gas engines (Field et al. 2016). In the report of De Andrés et al. (2016), it emphasis the importance of transforming the syngas into the final value added products. For instance, production of synthetic natural gas and dimethyl ether from syngas is observed in this report. It also reports that two byproducts, viz., char and tars are also produced in addition to syngas. The biomass composition is an important parameter and it is being fed to the gasifier which usually decides the formation of these products. The char might be used as a domestic fuel or it can be moved into fertilizers and turned on carbon in other applications. However, in gasification, the tars are an unwanted byproduct. The presence of tars decreases the value of the syngas consequentially creating corrosion and blockage in the equipment (De Andrés et al. 2016). The gasifiers may be categorized as fixed bed gasifier and fluidized bed gasifier. Based on the direction of airflow, the fixed bed gasifiers are further classified as downdraft, updraft and cross draft types.

10.3.2.3 Biomass Liquefaction

The method in which the macromolecules of biomass are hydrolyzed or degraded with water at average temperature and high pressures is commonly known as hydrothermal liquefaction. There are generally two paths through which liquefaction of biomass mainly takes place: (i) liquefaction through the process of pyrolysis without any gasification medium and (ii) liquefaction through methanol with gasification medium. The former process is a relatively low temperature (250–450 °C), high pressure (270 atm) thermochemical conversion of wet biomass, usually occurs by means of high hydrogen partial pressure and also need a catalyst to augment the rate of reaction and/or to improve the fussiness of the process. Liquefaction through gasification medium involves the production of methanol from mixture of H_2 and CO (producer gas). The temperature of this reaction takes place at 330 °C and 150 atm pressure.

$$2H_2 + CO \rightarrow CH_3OH$$

The H_2 and CO required for this process is produced by gasifying biomass fuel. Gasification often produces less H_2:CO ratio than 2:1 required for methanol synthesis. The gas mixture is often reacted with steam in presence of catalyst to promote a shift to increase hydrogen content.

$$CO + H_2O \rightarrow H_2 + CO_2$$

At the operating conditions, water being a liquid fluid having some great advantages like, having a low dielectric constant makes water act as a poor polar solvent resulting a better solubility with organic compounds rising from the biomass (Zhu et al. 2015). The article (Biller and Ross 2011) reports that molecules hydrolyzed by hydrothermal liquefaction are highly reactive and are repolymerized quickly to form bio-oils. Typically, hydro thermal liquefaction uses water as the reaction medium and catalyst. Thus, it becomes an ideal process for high moisture content biomass. It has been found that hydrothermal liquefaction is reported for a large number of raw materials including the marine and microalgae (Biller et al. 2012). The advantage of hydrothermal liquefaction over general thermochemical processes lies in procuring biooil directly in a single step without having pre drying (Gai et al. 2015). This results a reduction of the consumption in energy, and therefore greater economic benefits can be attained (Gai et al. 2015).

10.3.3 Biological Methods

10.3.3.1 Fermentation

The process of fermentation is used by the early civilizations to make foods such as bread, yogurt, wine, beer, etc. However, the increasing needs of human desires make the researchers to think for complex products that might cope up with the challenges of humanity (Jiang et al. 2015). The recent development in the science and technology in conjunction with the population growth increases the energy consumption tremendously. In order to meet the energy demands, various industrial processes have been developed to focus on the production of fuels using large amount of nonrenewable resources which might cause serious environmental problems (Nualsri et al. 2016). In this note, a much higher attention is given to the technologies that utilize renewable raw materials for biofuel production. Different processing technologies are available for the production of renewable biofuels. The most demanding technology till date is fermentation. It is a biological process through which biomolecules required in the industries are achieved, such as biofuels (ethanol, butanol, biogas, hydrogen, etc.) (Nualsri et al. 2016), drugs, food and biopolymers (poly-3-hydroxybutyrate and polyols) (Kreyenschulte et al. 2016). The process of fermentation varies based on the type of microorganism and the raw material used. According to the article (Kwietniewska and Tys 2014), in cases where the raw materials cannot be incorporated directly by the microorganism, there must be some pretreatment procedures before the hydrolysis to get fermentable sugars for the microorganism. Again, depending on the requirement of oxygen of the microorganism fermentation can be categorized.

10.3.3.2 Aerobic Fermentation

In aerobic fermentation microorganisms require high accessibility of oxygen in the culture soup (Oliveira 2004). In order to meet the required growth of the microorganisms, the accessibility of oxygen must be put above a minimum level. The aforesaid article also reports that due to the low solubility of oxygen it is hard to access and supply of oxygen in spite of the large requirement by the microorganisms. The significant products obtained by aerobic fermentation are terpenes, antibiotics, organic acids, amino acids, etc. (Kwietniewska and Tys 2014).

10.3.3.3 Anaerobic Fermentation

It is a biological process in which the microorganism does not need to access oxygen to adjust to the medium and to generate different products. The most significant fermentation for the generation of biofuels is dark fermentation such as production of hydrogen (Farhana Azman et al. 2016) and methane (Kwietniewska and Tys 2014). Methane production procedure is commonly known as anaerobic digestion.

(a) **Anaerobic digestion of biogas**

Anaerobic digestion (AD) is an auspicious technology that recuperates bioenergy from lignocellulosic biomass or wastes (Zhang et al. 2015). Anaerobic digestion is a biological process through which organic matter is broken to produce biogas in the absence of Oxygen. In this process microorganisms (like acidogenetic bacteria, acetogens, etc.) convert the biodegradable matter to biogas. This process may be considered as a waste deposition method and it serves as an environmental conservation technique. The basic equation for this conversion which results in carbon dioxide and methane may be written as follows:

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

Biogas is produced from wet biomass with about 90–95% water content by the action of anaerobic bacteria. Part of carbon is oxidized and another part reduced to produce CO_2 and CH_4. These bacteria live and grow without oxygen. They derive the needed oxygen by decomposing the biomass. This process is favored by wet, warm, and dark conditions. The airtight equipment used for conversion is known as biogas plant or digester, which is constructed and controlled to favor methane production. This conversion process is commonly termed as anaerobic fermentation (or biodigestion). Nutrients such as soluble nitrogen compounds remain available in solution and provide excellent fertilizer and humus, the energy available from the combustion of biogas is 60–90% of the input dry matter heat of combustion. Thus its energy conversion efficiency of the process is 60–90%. Following steps can be followed in this process: In the first step, for the smooth conversion, organic matters containing complex compounds e.g. carbohydrate, protein, fats, etc., are broken into sizable molecules. This process is commonly known as hydrolysis. This process takes about a day at 25 °C in an active digester. In the second step, acidogens act on the decomposed matter and converts into volatile fatty acids (VFAs), mainly producing acetic and propionic acids. This stage also takes about one day at 25 °C. Ammonia, CO_2 and hydrogen sulfide are also produced along with the VFAs. This process is commonly known as acidogenesis. In the third step, VFAs are additionally broken down into acetic acid, carbon dioxide and hydrogen. This process takes about two weeks' time to complete at 25 °C. The fourth and the final stage is the combination of emissions to produce water, methanol and carbon dioxide (Fig. 10.3). Biogas plants or digesters are broadly classified as batch type and continuous type. Further continuous type plants are further classified into constant pressure type or floating drum and constant volume type or fixed dome type. In case of the batch type plant, it is charged at 50–60 days interval. Once charged, it starts supplying the gas after 8–10 days and continues its service about 40–50 days till the digestion process is completed. Again in case of continuous type, the plant is fed daily (not intermittently) with certain quantity of biomass. The gas produced is stored in the plant or in a separate gasholder and remains available for use as required. The biomass while slowly passing through the digester is completely digested and the digested slurry is rejected through an outlet. The period during which the biomass remains in the digester is known as retention period, which depends mainly on the type of biomass and operating temperature. The plant operates continuously and stopped only for maintenance or for removal of sludge .

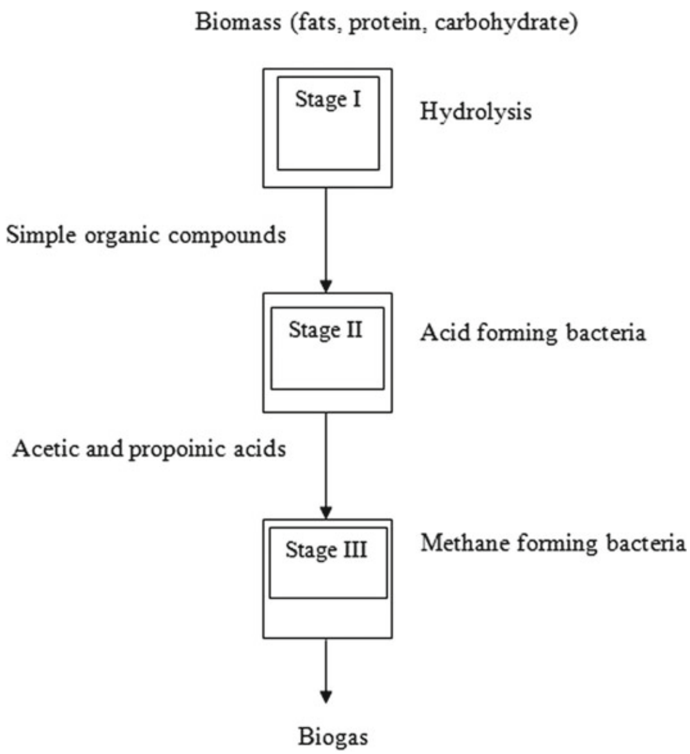

Fig. 10.3 Various stages of anaerobic digestion process

(b) **Alcoholic fermentation**

The process of conversion of sugars into cellulose is known as the alcoholic fermentation. It is a decomposition in absence of air of simple hexose sugars in aqueous solution by action of enzyme (a natural catalyst) present in yeast, in acidic conditions (pH value 4–5). It is considered as an anaerobic since it takes place in the absence of oxygen. The by-products obtained from this process are ethanol and carbon dioxide. In addition to the bread baking and manufacturing alcoholic brews, this process also produces alcoholic fuel. In dry situations sugarcane is the main feedstock for alcoholic fermentation process. Corn or sugar bits are also used in tepid climates. The hexose (i.e., glucose and/or fructose) needed for alcoholic fermentation is usually derived from (i) sucrose (ii) starch or (iii) cellulose. The preparation is explained below (Khan 2017):

(i) Sucrose: It is the most available disaccharide and is manufactured from sugar cane or beetroot. Generally commercially available sucrose is removed from the cane juice, and the remaining molasses, which has low commercial value, is used for ethanol production. The molasses itself has about 55% sugar content and serves as very good raw materials for ethanol production. On hydrolysis with dilute acids or enzyme it gives equal amounts of glucose and fructose.

$$C_{12}H_{22}O_{11}\text{ (Sucrose)} \rightarrow C_6H_{12}O_6\text{ (Glucose)} + C_6H_{12}O_6\text{ (Fructose)}$$

(ii) Starch: On hydrolysis with dilute H_2SO_4 or enzyme, starch breaks down to maltose and finally to glucose.

$$\begin{aligned} 2(C_6H_{10}O_5)_n\text{ (Starch)} + nH_2O &\rightarrow nC_{12}H_{22}O_{11}\text{ (Maltose)} + nH_2O \\ &\rightarrow 2nC_6H_{12}O_6\text{ (Glucose)} \end{aligned}$$

(iii) Cellulose: It is not hydrolyzed so easily as starch, but on heating with dilute sulphuric acid under pressure yield glucose (393 K, 2–3 atm).

$$(C_6H_{10}O_5)_n\text{ (Cellulose)} + nH_2O \rightarrow nC_6H_{12}O_6\text{ (Glucose)}$$

Sucrose materials are readily available in fermentable form, require least expensive preparation, but are generally most expensive to obtain. Starch bearing materials are often cheaper, but require processing to solubilize and convert starch to sugars. Cellulosic materials are the most readily available raw materials, as cellulose is the most abundantly available organic compound in the world, but they require the most

Table 10.2 Ethanol production from various hydrocarbon rich plants (Khan 2017)

S. no.	Raw materials	Ethanol produced per ton of crop (L/ton)	Ethanol produce per hectare per year (L/ha)
1.	Barley	310–350	700–1300
2.	Cassava	175–190	2200–2300
3.	*Hardwood hydrolytic agent*		
	Dilute acid	160–180	1500–2500
	Conc. acids	190–220	1800–3000
4.	Jerusalem artichoke	80–100	2700–5400
5.	Maize	360–400	1500–3000
6.	Potato	100–120	2200–3300
7.	Sugarcane	60–80	3500–7000
8.	Sugar beet	90–100	3800–4800

extensive and costly preparation. Finally, ethanol is obtained from fermentation of hexose sugar

$$C_6H_{12}O_6 \text{ (hexose)} \rightarrow 2C_2H_5OH \text{ (Ethanol)} + 2CO_2$$

The ethanol produce from various types of raw materials is given in Table 10.2.

10.3.4 Application of Products

The applications of the product can be listed as follows: Acetone is a one such product which can be used for production of food additives, act as grease removers, glue dissolver, thinning of paint, and in the cosmetic products. Hydrogen can be used as a cooling agent in power industries also used in hydrogen cells for production of energy. Butanol can provide better fuel than ethanol. It may be used as an ingredient in polymer extractions, manufacture of synthetic fiber, cosmetic products, etc. Ethanol can be used as fuel, paint component, a preservative in antiseptics and in alcoholic beverages.

10.4 Environmental Issues Related to the Bioenergy Production

10.4.1 Water Quality and Quantity

The biomass production systems can influence the availability and quality of water. The different systems use different amounts of water from surface and groundwater, depending on, among others, the water-use efficiency of the crops and whether the system is irrigated or rain-fed. The various effects of bioenergy production on water quality and quantity depends mainly on the possible water consumption of bioenergy crops and land based conversion. For instance, in US, the extensive expansion in corn ethanol production, which may be considered as the first-generation biofuel, encouraged by EISA (Energy Independence and Security Act 2007) was projected to generate probable stress at local and regional scales (Hoekman et al. 2018; Gasparatos et al. 2011; Zhou et al. 2015). This is because of the corn needs more water relative to the other crops like wheat and soybean due to the consumption of additional water in almost every growing stage (Wu et al. 2018). In general, Bioenergy crops optimized for rapid growth usually devour more water than natural flora/many food crops. Some biomass crops, for example, sugarcane compete directly with food crops for irrigation water. According to a report (Sivan 2006) in some cases, like harvesting residues, cultivating tree crops without undergrowth, and planting species that do not produce satisfactory amounts or types of disorder, might reduce the ability of rainfall to infiltrate the soil and refill groundwater supplies, aggravating problems of water over consumption. The modeling results by Kim et al. (2013) exemplified that wide plantation of bioenergy crops will upsurge the amount of evapotranspiration (ET), decrease annual surface water and water harvest in the Yazoo river basin of Mississippi River becomes the main corn production region in US. Similar conclusions can be found in the literature of Wu and Liu (2012), Guo et al. (2018). These reports also forecast that the land conversion to bioenergy crops might cause reduction of water resources at the watershed scale.

10.4.2 Quality of the Soil and Its Fertility

Some of the bioenergy production systems use and restore tainted lands, while others may contribute to the degradation of the land. Thus, in many cases, production of bioenergy probably changes the quality of the soil in terms of carbon and nutrient content. It also effect the risk associated with the soil erosion. Consequently, biomass crops impose a particular challenge for better soil management since the material of the plant is habitually harvested completely, leaving little organic matter or plant nutrients for salvaging to the soil. It is noted that in many rural areas of the developing world where soil management relies on recycling crop wastes and manure rather than using the external inputs, biomass production might lead to intense reduction in soil fertility. Despite of the fact of adding more plant matter on the land may reduce the yielding capacity of the bioenergy crop material but it is always needed to maintain soil organic matter by adding sufficient amount of plant matter. In many situations, it is possible for the farmers to reduce the risk of nutrient depletion by allowing the twigs and leaves of the trees to decompose on the field. The nutrients available on the feedstock's can also be regained from the conversion facilities in terms of sludge or ash and it is converted into a suitable form which can be applied to the field rather than put in a landfill. This method is available in many bioenergy systems.

However, the nutritive value of the ash or sludge may be lower than the optimal. There are three main ways that can cause the soil erosion: (i) the corn acreage extension, (ii) residue removal, and (iii) land use change. Because of the rising demand for ethanol might have intense adverse consequences in the process of soil retention since the corn acreage extension is having the slacker planting space. The benefits of the various conservation measures on soil retention would be reduced more if the increased corn cropping ensued on these lands, and cultivating the existing corn crops with suitable cultivation practices may reduce the soil erosion (Hoekman et al. 2018). It is reported in the article (Blanco-Canqui and Wortmann 2017) that the crop residue leaving behind the soil surface may buffer wind and water erosive forces. Thus, harvesting the crop residue may upsurge the erosion risk due to the minimum physical shield of soil surface (Environmental Protection Authority Act 2011; Lal 2005), leading to nutrient and SOC losses. But, following (Cibin et al. 2016), soil erosion persuaded by higher residue removal rate may be alleviated by suitable management choices like direct input of organic matter and other security measures. Moreover, land use conversion might aggravate erosion or shelter soil from erosion. For example, conversion from forest to perennial bioenergy crops may surges the risk of losses related to the soil and water (Liu et al. 2012), while the conversion from the grain crops to perennial grasses could generate encouraging effects on the soil and water preservation because of the erect and ribbed stems with sods that are generated by perennials (Cooney et al. 2017). The perennial grass, particularly the switch grass, might decrease the residue yield in stream flow and soil erosion and increase the use of water and infiltration regardless the climate conditions in the Chinese loess plateau, representing the advantage in soil and water preservation of perennials compared to the outmoded crops in such regions (Cooney et al. 2017; Brown et al. 2000). So, growing perennial grasses particularly in erosion prone areas has a superior potential than that of the corn ethanol production.

10.4.3 Biodiversity

The environments and biodiversity are greatly influenced by the production of bioenergy feedstocks. The environment for bioenergy crop production is alike to natural habitat relative to other agricultural options that improves biodiversity to seal the difference between the remnant fractions of natural habitat. For instance, the present environmental regulation in Brazil needs to leave 25% of the total plantation area for natural vegetation to maintain a balance in the ecosystem. The natural vegetation helps in controlling pests in surrounding plantation by using predators. The migrating wild lives are benefitted from the bioenergy crops that functions as corridors between the natural habitat areas. For instance, the production of *Pinus patula* and *Acacia melanoxylon* in South Africa, *Pinus pinaster* in Uruguay, and eucalyptus in various regions has increased rapidly that act as pests to the local vegetation. The evading of monoculture stops the spread of pests or disease into natural habitat. In India, there exists a circumstance of spreading of fungal disease from exotic pines on plantations to native pines. The food production and ecosystem services are greatly influenced by biodiversity (Qin et al. 2018). The initial condition of land, way of bioenergy production and landscape pattern effects the biofuel production (Correa et al. 2017; Immerzeel et al. 2014). Land use conversion is related to plant type and planting locations that disturbs the biological abundance. The biofuel crops maintain the ecosystem and increases the efficiency with the alteration of production system (Sang and Zhu 2011; Correa et al. 2017). Additionally, the Miscanthus has lesser negative impact on biodiversity than annual crops as regular cultivations offer stable habitats for maintaining wild life (Rowe et al. 2009; Werling et al. 2013). The landscape design improvement and reduction of biodiversity risk can be achieved by growing energy crops on low production lands (Sang and Zhu 2011; Manning et al. 2015). Soil organic carbon (SOC) signifies soil quality and crop productivity, soil biodiversity; soil water retention is increased with high amount of soil organic carbon. The soil organic carbon is influenced by bioenergy production in three ways, viz. elimination of deposits, tilth and modification of land use. The reaping of dead plant residuals can speed up the reduction of soil organic carbon due to less carbon input (Hoekman et al. 2018). The managing of residue by adding organic matter in the form of manure can control the reduction of soil organic carbon (Robertson et al. 2014; Sheehan et al. 2014). The biochar is mainly produced from crop residues using suitable techniques. The biochar improves the function of carbon sink in agricultural sector by aggregating soil organic carbon and absorbing CO_2 in air (Li et al. 2017) and improves the air quality by mitigating NO_x, methane and PM 2.5 (Pourhashem et al. 2017). The soil disturbance and ill management is the second cause of soil organic loss. The report (Drewniak et al. 2015) examined the impacts of tillage practices on soil organic carbon through simulated biogeochemical model and observed that tillage causes soil organic carbon loss. Also, several experiments suggested that the reduction soil organic carbon is possible through tillage practices (Cheng 2009; Ouyang et al. 2015; Warren Raffa et al. 2015). The land conversion is a vital factor for soil organic carbon change.

10.4.4 Greenhouse Gas Emissions

The primary GHG emissions, viz. CO_2 and N_2O, must be reduced while producing bioenergy (Dunn et al. 2013; Qin et al. 2016). Many studies proved that the biofuels produce less CO_2 emissions than fossil fuels (Fu et al. 2014; Wang et al. 2012). Liu et al. (2017) replaced fossil fuels to reduce CO_2 emissions by 29 million ton eq/year by more switch grass production on marginal land. The model suggested that in US, the GHG emissions may be reduced by 40–85% using ethanol in comparison to gasoline on a per mega joule (MJ) energy basis. However, the amount of reduction of greenhouse gas emissions is different for different feed stocks and bioenergy production indirectly effects CO_2 emissions (Dunn et al. 2013; Searchinger et al. 2008). Harris et al. (2015) reviewed the impact of biofuel and confirmed a reduction of CO_2 emissions through land transitions from arable to second generation bioenergy crops. While, conversion of land from native grassland to first generation bioenergy crops and short rotation coppice (SRC) exhibited a noticeable rise in CO_2 emissions. Hence, categories of bioenergy crops and its management are important for mitigating CO_2 emissions. The N_2O is the second important GHG that largely contributes to global warming and mainly produced from agriculture (Williams et al. 2010) and land transitions. Liu et al. (2011) replaced fossil fuel and stated that the biomass production on marginal land for energy consequences in good environmental impact on national greenhouse gas emissions. The N_2O emissions may be stimulated by expanding corn cultivation that is driven by ethanol demand. The corn cultivation demands higher nitrogen fertilizer in comparison to other crops that leads to soil denitrification increasing N_2O emission. Hence, the selection of bioenergy plant type and planting locations is of utmost necessity for controlling N_2O emissions.

Wielgosinski et al. (2017) compared the pollutants [i.e. carbon monoxide (CO), nitrogen oxide (NO) and the total organic carbon (TOC)] emitted during the combustion of seven biomass samples, viz. rape straw, oak bark, firewood and wood pellets, shrub willow and rape cake, with pulverized hard coal samples. The study was carried out in laboratory chamber furnace at five different temperatures between 700 and 1100 °C and three different air flow rates with excess oxygen. The various pollutants, especially the TOC, were found to be higher in the biomass combustion than in hard coal combustion. Hence, biomass cannot be always considered as an eco-friendly fuel even though it is renewable. The emission levels are too high or comparable to that of combustion of coal, whereas the biomass emits higher hydrocarbon than coal.

10.4.5 Socio-economic Problems and Governance Implications

Various issues related to the rights of the labours, land dealings, building capacity, gender neutrality, loss of traditional cultural practices and the conflicts arise from the land disputes might cause socio-economic problems arising from the production and consumption of bioenergy and biomaterials. Following the article (Müller et al. 2015), it may be argued that production and consumption of biomass could have negative and favorable impacts based on the conditions in which they occur. Moreover, these effects take place at different levels and scales covering from local to international standards. International policies, for example, European Union's Biofuel Directive, World Bank's scheme like RAIP (Responsible Agricultural Investment Principles), etc., have been implemented to influence the biomass production. These policies are important for finding what/where/how/by whom biomass production have been carried out.

According to the aforementioned report (Müller et al. 2015), as a part of the future development agenda (post-2015), the international community decides on global sustainable development goals (SDGs) in order to establish a comprehensive normalize framework that may be universally acceptable. The year 2015, thus, becomes a benchmark for sustainability governance worldwide. These SDGs are more complex and wider set of goals than the former Millennium Development Goals (MDGs). These governance schemes are vital to bridge the increasing and diverse demand of biomass and highlighting the achievement of social needs within the environmental boundaries which actually considers the socio-economic ambitions of SDGs with respect to equity, protection of natural resources required for biomass production and various impacts by these parameters. Again, inequalities in terms of opportunities, power, access to the resources needs to be taken care while implementing these governance schemes.

10.5 Conclusions

Last but not least it should be noted that sustainable bioenergy is not just a subject of suitable metrics (standards and indicators) and respective dimensions but also relies highly on how those are demarcated, and applied, and by whom (Müller et al. 2015; Stupak et al. 2016). Latest work of de Man and German (2017) direct that certification if sustainability for biofuels is an inadequate substitute for public directive. Certain frail systems are working which only consider fall of greenhouse gas targets and very few addresses for biodiversity. On the other side, even ambitious sustainability schemes might not able to overcome the problem of land-use leakage: It is seen that sectoral or commodity-related certifications illustrate that unsustainable practices could be shifted to the external biomass which is outside of the scheme. Hence, in a broader way, it may be said that sustainability governance of bioenergy is a vital part of a sustainable bioeconomy governance (El-Chichakli et al. 2016) which generally holds all land use to avoid cherry picking and leakage. Following (Müller et al. 2015), we need to incorporate reviewing business standards say WTO regulations, private governance scheme and national legislations to find where modifications are desired and how the sustainability aspects could be strengthened.

There are genuine advantages of the bioenergy relative to the traditional fossil fuel because of the huge quantity and its renewability. Thus bioenergy plays a vital role in protecting the energy safety of the earth. However, it is always desirable to consider the cost of resources and environment while employing the bioenergy production. The present study is made to summarize the environmental impacts of bioenergy production based on the previous studies. It is noted that in spite of the increasing trend, the attention is not given much on bioenergy focused on environmental effects. It may also be concluded that among all the factors of bioenergy production, water issues receives highest attention and least concern has been given to the soil erosion. In addition to the various negative effects on the surrounding by the bioenergy production, the hostile impacts on the environment varied greatly among plant types and land sources. Recognizing the suitable cultivation areas, types of proper bioenergy crops and optimum management practices may be useful to the both bioenergy production and environment. South-East Asia has a large potential of bioenergy production, but the production in this region has lagged behind and does not attain its growing energy consumption. It is always recommendable to do research on the leading countries in this field, accumulate better knowledge and identify the optimum solutions for the development of bioenergy in the developing nations. These types of study may give a lucid picture on designing the bioenergy development as well as environment safeguard.

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