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CHAPTER

17

Impact of advanced biofuels on climate change

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17.1 Introduction

Numerous negative effects of fossil fuel consumption have been observed on the ecosystem due to the generated product wastes, effluents, and air pollutants. The majority of greenhouse gas (GHGs) emissions are coming from the transportation sector [1,2]. GHGs liberated through petrochemicals include sulfur oxides, carbon monoxides, nitrogen oxides, etc. [3]. The emitted GHGs have adverse impacts on the environment such as acid rain, soil contamination, and pollution of natural water resources [3–6]. However, a reduction in such pollution can be found in biofuels as a favorable alternate.

To mitigate GHG impact on climate change, several efforts have been made by various organizations. For example, the 2°C scenario (2DS) was proposed by the International Energy Agency (IEA) to deal with this global environmental concern. The 2DS outlines an energy system that aligns with the emissions path suggested by recent climate science research, which indicates an 80% probability of keeping global temperature rise within 2°C. Rules made by members of 2DS were mostly focused on carbon dioxide emissions with a planned reduction of about 50% in such emissions by 2050. Such targets can be achieved by using alternate energies such as solar, wind, biofuels, etc. [7].

Hence, finding renewable energy sources becomes essential. Among all alternative energy sources, biofuel is a favorable substitute for

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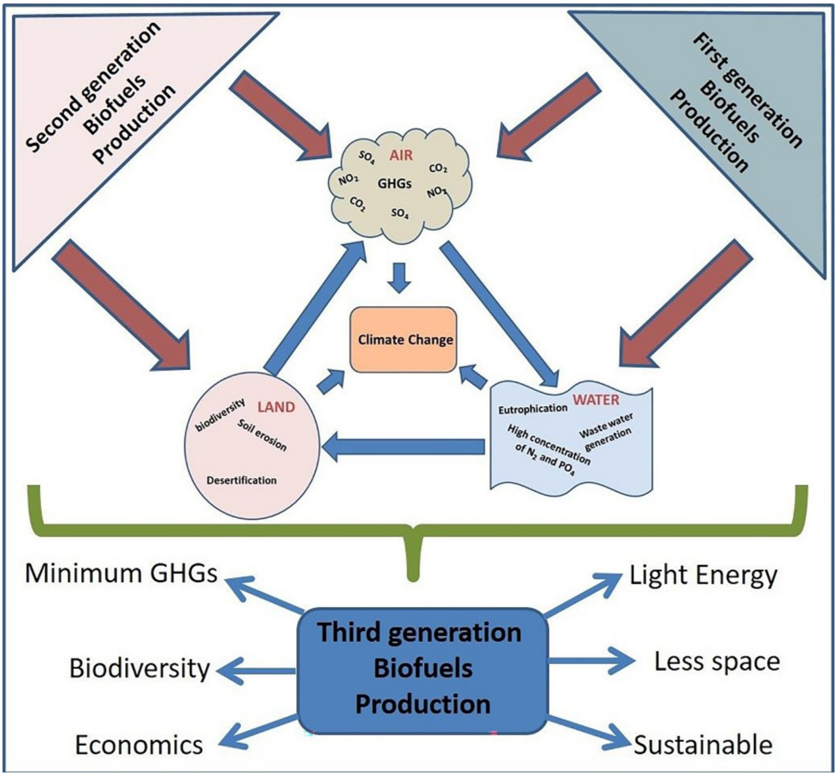

FIG. 17.1 Schematic presentation of advanced biofuels impact on climate change.

fossil fuels [8]. Biofuels are categorized based on their manufacturing processes, such as first-, second-, and third-generation biofuels (1G, 2G, and 3G) [9]. Feedstocks such as maize, corn, and sugarcane were used in the production of first-generation biofuels. Raw materials like nonfeedstocks were used in second-generation biofuels, mainly lignocellulosic materials such as bagasse, wheat straw, etc. Algae, cyanobacteria, fungi, and yeast were used for third-generation biofuels [10]. These categories of biofuels are recognized as advanced biofuels. However, the production of advanced biofuels had some contrary impact related to environmental compatibility and resource management (Fig. 17.1). Therefore, in this chapter, the discussion focuses on the compatibility of advanced biofuels in terms of climate change and its related aspects such as environmental resources and biodiversity management. The chapter also discusses a life cycle assessment of advanced biofuels with respect to climate change.

17.2 Advanced biofuel production strategies with regard to climate change

The first generation of biofuels was produced by the extensive fermentation of sugars, lipids, and carbohydrates. This required a huge quantity of organic mass generated by feedstocks. This mass is ultimately transferred into different energy forms such as electricity, biogas, bioethanol, etc. [9].

Feedstocks, mainly corn and sugarcane, were used for first-generation biofuels, but the major limitation is the scarcity of a substrate for production. Overcoming this problem led to increasing biomass production in the form of other feedstocks containing a higher percentage of starch, mainly potato, rice, barley, and wheat. Oil seeds were used for oil extraction for biodiesel production by fermentation and transesterification, and starchy material was converted to bioethanol [11].

Concerns regarding the low impact of first-generation biofuels with respect to GHGs and climate change resulted in a second generation of biofuels. Second-generation biofuel production is based on nonfeedstock materials such as biomass from agroforestry residues; this avoids competition among feedstocks [10]. However, GHG emissions from second-generation biofuels were also reported, although they were relatively low in comparison with the first generation and fossil fuels [11].

The algal biomass remains the primary choice of third-generation biofuels. Characteristics of third-generation biofuels that make them ecosustainable are the need for less land to cultivate as well as the fast growth rate of microalgae and other microbes compared with feedstock and higher plants. This ultimately reduces the stress of biofuels on agroindustry-based resources and on land [12]. The third-generation biofuel can also be beneficial in terms of GHG emissions because photosynthetic microalgae are known for the consumption of CO_2 at a higher rate (approx. 40%) than any other known living entities [12,13]. In addition, many algae species are also known for producing added-value products, including single cell proteins (SCP) and other nutrients [14,15].

17.3 Advanced biofuels and their impact on greenhouse gases

The CO_2 consumption during photosynthesis by plants and algae can significantly limit GHG emissions from fossil fuels. In this context, biofuel production from lignocellulosic and algal biomass will maintain a balance between bioenergy and carbon capture and storage (BECCS) [16]. This indicates a balance between deforestation and afforestation processes. Biofuel and bioenergy sectors are essential to mitigate the GHG emissions caused by the transportation sector, which predominantly relies on fossil fuels. These emissions disrupt the carbon capture and storage (CCS) in the environment, making biofuels and bioenergy essential for mitigating their impact on climate change. Yet, the mitigation benefit of biofuels in GHGs is debatable because of the ecological carbon loss from the environment, especially from land [17]. To fill this gap, there is a need for more land or the implementation of earlier strategies used for the reduction of CO_2 [18]. These strategies include aforestation to minimize global warming; the maximum use of renewable energy sources such as electricity, and solar energy, besides the development of technologies to produce advanced biofuels for transportation with the fewest or zero GHG emissions [19–21]. The emission factor (EF) can be measured as the emissions seen related to biofuel production and expressed as the ratio of GHGs emitted per unit of bioenergy produced. The EF will be the comparison of differences that counts emissions of units of bioenergy at the time of production in the energy system and gives the exact outline for assessing the biofuel production strategies [22–25].

A comparative analysis based of available literature on CO_2 emissions from first- and second-generation biofuels shows that GHG emissions (Table 17.1) are influenced by the conversion of feedstock into fuel [35]. A comparable decrease in GHG emissions (59%–82%) was observed related to gasoline emissions compared with feedstock used in biofuels containing high sugar [26]. The life cycle assessment (LCA) of sugarcane shows a remarkable discharge of GHG emissions throughout the farming and downstreaming of ethanol. First-generation biofuel crops use a higher concentration of fertilizers and terrestrial assets [29]. This drives the high consumption of nitrogen-based fertilizer, which increases N_2O emissions.

TABLE 17.1 Impact of biofuel on greenhouse gas emissions (in terms of Co_2 release).

Type of biofuel	Substrate/ feedstock	Bioethanol/biofuel production (L/kg)	% Emission CO_2 gCO_2eq/MJ	Reference
First generation	Corn	0.45–6.46	43–78	[26,27]
	Sugarcane	0.50	45	[26,28]
	Wheat	0.30	68	[29]
	Cassava	0.15–20	–	[26]
	Soybean	–	10	[29]
Second generation	Rice straw	110–120	–	[30]
	Corn meal/ stover	5–10	7.6	[31,32]
	Palm wood	0.20	–	[33]
	Paddy straw	0.0008	–	[34]

The downstreaming processes adopted for sugarcane released N_2O [36]. The N_2O emissions from processing starch containing raw substances also raised GHG emissions [37]. In contrast, the soybean biofuel LCA showed comparatively decreased GHG emissions than sunflower and rapeseed oil biofuels [38]. The soybean biofuel is known to reduce up to 65% GHG emissions when compared with fossil fuels such as diesel and petroleum [29].

It is hypothesized that nonfeedstock biofuel such as second-generation bioethanol produced from lignocellulose waste could minimize GHG emissions by 70%–85% by 2050 [39]. The European Union (EU) has made great efforts to reduce GHGs by up to 35% by increasing the use of renewable energy [40]. However, the LCA of second-generation fuels shows contrasting findings because the higher consumption of organic biomass for biofuel production may adversely impact the ecosystem. For example, straw removal from a farm can be responsible for the reduction in soil organic matter as well as disturbing the soil nutrient cycle, which ultimately leads to soil infertility. Straw removal from cropland can adversely impact ammonia volatilization because of the mobilization of mineralized fertilizers [41]. The recalcitrant nature of the lignin biomass poses a challenge, due to its increased persistence in the environment even after its associated components like cellulose, and hemicellulose have been used.

17.4 Impact on water

While the extensive evaluation of biofuel impact was focused on GHG emissions, other associated problems concerning climate change besides water pollution have also attracted attention from scientists and academia. The problems related to natural water increase during feedstock production, processing, and biofuel production [42,43]. Advanced biofuels require less water when prepared using straw over any other oil seed-based biofuel. However, this water consumption will be more in comparison with other renewable energy sources [44]. Out of the total amount of water used in biofuel manufacture, the major part (approx. 84.6%) will be used for feedstock production in agriculture. An overall observation of the effects exerted by biofuel generation suggests that nonfeedstock biomass used for biofuel production can mitigate the water depletion scenarios. In addition, the reduced use of fertilizers and land for the cultivation of bioenergy crops might also help to restore environmental sustainability [45].

17.4.1 Impact on water quality

Because biofuel production requires more water than fossil fuel production [46,47], it causes induced stress on water supplies and diminishes water quality [48]. Lack of uniformed and sustainable water treatment affects the availability and quality of natural water. It could also raise problems related to water consumption from natural reservoirs as well as pollution problems such as eutrophication. Water scarcity also impacts biodiversity. The exclusive use and drain of water from natural reservoirs may result in increased concentrations of salt and other minerals [49]. Depending on the water footprint, the evolution of algal biomass-based biofuel production is recognized as water-sustainable bioenergy production. This method consumes least amount of blue water (surface and ground water) and available green water (rain water until its run off) that minimizes the problem of land water nexus by decreasing water evaporation and acquisition of more land. It also creates a cooling impact in ecosphere due to consumption of atmospheric CO_2 by algal biomass. At the same time, the microalgal biomass can be cultivated using wastewater also [50]. However, third-generation biofuel production also requires a considerable amount of water, including sea water or wastewater [51].

17.4.2 Eutrophication and other associated impacts

First-generation biofuels required the cultivation of feedstock, for which a large amount of fertilizers was used; this increased the utilizable form of N_2 and PO_4 concentration in water bodies and resulted in eutrophication [52]. Eutrophication in water bodies can lead to their deoxygenation and the accumulation of toxicants by algae; it can also cause various diseases of vertebrates such as the accumulation of nitrate in the body [53].

Unlike first- and second-generation biofuels, algal biofuel will not need pesticides and fertilizers [54] because algae are photosynthetic organisms that dwell in oligotrophic habitats. The cultivation of algae causes little to no contamination of unwanted microorganisms [55]. This could be the reason that third-generation biofuels do not lead to the eutrophication of water bodies [54,56]. However, the use of wastewater to cultivate algal biomass reduces water use, recycles water, helps with gray water footprints, and decreases nutrient accumulation [50,57,58].

17.5 Impact on land

Soil is a dynamic and sustainable part of the ecosphere when used wisely. Avoiding soil overexploitation can mitigate the impact of climate change and aid biodiversity [59]. However, mismanagement in biofuel production strategies impacts soil fertility while increasing erosion and the biophysicochemical properties of the soil [60]. In addition, it can also impact water bodies by changing their physicochemical properties [61].

To generate every unit of energy from biofuel, the large-scale use of land is required. This land requirement was calculated as energy per unit crop. The findings suggest that biofuels required approximately 10–20 times more land per unit of area compared with fossil fuels [62]. The reduction in biodiversity was due to the adaptation of feedstock monoculture (e.g., corn) strategies for biofuel production [63]. The natural degradation potential of organic biomass is the measure of the sustainable habitat and biodiversity. This potential of organic matter sustainability collapses when organic matter is used for biofuel production [64]. Furthermore, the invasion of species in indigenous plant or crop species may also affect biodiversity [65]. The crops taken to produce biofuels help with species invasion and make conditions favorable for invasion by newer organisms [66].

Biofuel crop-harvesting practices can affect soil erosion, nutrients, and soil organic matter. The feedstock harvesting associated with first-generation biofuels may lead to soil erosion while also affecting the biogeochemical cycling of minerals and organic compounds. This may lead to a decrease in soil fertility and ultimately the increased use of fertilizer [67]. The excessive use of fertilizers results in additional environmental impacts. For the maximum land acquisition for feedstock production, pressure was created on the native ecosystem, which leads to decreases in soil fertility, biodiversity, and the community dynamics of the ecosystem [68,69].

The production of second-generation biofuels has the potential to minimize the problems associated with the production strategies of first-generation biofuel. Biomass containing lignocellulose will be used as the best alternative for fermentable sugar for biorefineries and biofuel production [70]. However, the complex and recalcitrant nature of lignocellulose limits its use in biofuel production in terms of less saccharification [71]. Considering the higher mass in agro forest waste, great efforts have been made to use this recalcitrant component in the bioenergy sector, which includes physicochemical as well as biological processes. As biological processes are associated with fewer pollution problems, they are naturally preferred [70,71]. The concept of natural biomass utilization systems has become more advanced. These are used prominently in the bioconversion of lignocellulose, especially cellulolytic enzyme-producing microorganisms extracted from wood-eating insects and other animals [71,72]. Biodegradation technologies using microorganisms and their enzymes could be adapted in the production of second- and third-generation biofuels for bioprospection in cellulose degradation. Bioconversion will not need any additional requirements such as fertilizer or major amounts of water and will not increase any GHGs or pollutants, so it will mitigate the GHG climate impact and hence remain ecofriendly [72].

17.6 Conclusions

Based on the results from studies, the negative features of advanced biofuels make their actual implication difficult. These aspects primarily include failing to mitigate GHG emissions as well as water and soil pollution. Biofuel production technologies do have some problems based on their raw materials, processes techniques, and economics. This is especially apparent with first- and second-generation biofuels that have shown negative effects on soil, air, and water ecosystems. Therefore, for the ecofriendly and sustainable production of biofuels, it is necessary to develop processes that can reduce adverse impacts on the environment, including climate change. The methodologies of biofuel production from lignocellulosic waste reduce the threats of eutrophication, soil erosion, and deforestation while also decreasing the GHG impact and the resulting climate change. However, third- and fourth-generation biofuels could help in the sustainable generation of biofuels while remaining ecofriendly and reducing GHGs and the pollution of water bodies. Less land is required for third-generation biofuel because it mainly uses water. That ultimately creates a lesser burden in ecosystem management and biodiversity. Biofuel technologies are constantly developed through technological innovations that enhance the economic benefits as well as mitigate the climate change impact to meet the needs of sustainable energy production.

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