**ENVIRONMENTAL IMPACTS OF BIOFUELS**

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**Abstract**

The review examines the environmental impact of biofuels, focusing on their potential to replace fossil fuels. Life cycle assessments are utilized to quantify the overall net environmental impact of using biofuels instead of fossil fuels. These assessments consider energy requirements and direct greenhouse gas emissions and include the impact of land conversion for biofuel cultivation, such as deforestation. Additionally, the review discusses how biofuels have higher environmental impacts, such as ecotoxicity, eutrophication, and biodiversity loss, compared to fossil fuels. The article emphasizes the importance of considering the full life cycle of biofuels, including the indirect effects of land transformation and the associated carbon and biodiversity losses. Furthermore, the review highlights the need for certification schemes to ensure biofuels' sustainable production and mitigate their negative environmental impacts.

**Keywords**: Biofuels, Feedstock, Land use changes, Greenhouse gases, Environmental sustainability

**Introduction**

Biofuels are a low-carbon alternative to fossil fuels which are derived from biological material, present mainly in plants, microorganisms, animals, and wastes, and could help to reduce greenhouse gas (GHG) emissions and the related climate change impact from transport [1,2,34]. Biofuels can be differentiated based on several key characteristics like feedstock type, conversion process, technical specification of the fuel, and its use. Depending on the starting place and manufacturing of biofuels, they are generally appertained to as first, second, and third-generation biofuels (according to the EASAC report 2012), while the fourth-generation biofuels are just arising at the elementary exploration position. On the way towards a sustainable economy, the development of effective biofuel product strategies based on solar energy is of immense significance. Utmost of the primary-period biofuels are entered from the crops as energy-containing granules like sugars, oil, and cellulose [34]. They yield very less biofuel and hurt food security. Since first-era biofuels are produced through well-installed technology and processes, like fermentation, distillation, and transesterification, they are typically mentioned as ‘traditional/conventional biofuels' [36]. Efforts are needed to boost the technology of superior biofuels by figuring out and engineering powerful non-food feedstocks, enhancing the universal performance of conversion technology and the high-quality biofuels for multiple transport sectors for bringing down the costs (EASAC 2012). The second-generation biofuels are an enhancement in production of biofuels from a feedstock of lignocellulosic, non-food stuff that include straw, bagasse, timbre residues, and crops on marginal lands. Projects are required to increase the quantity of renewable carbon and hydrogen that can be converted to usable form of energy from “second generation” biomass. The 3rd generation technology biofuels are primarily based on algal biomass production [34]. Biodiesel attained from microalgae through traditional transesterification or hydro-remedy of algal oil is usually called 3rd generation biofuel. Second and third-technology biofuels are cited as ‘superior biofuels’ [36]. Presently, they are under expansive exploration to enhance both the metabolic yield of fuels and the Separation procedures in bio-oil manufacturing to remove non-fuel components and thereby reducing manufacturing costs. The fourth-generation biofuels (i.e., Photobiological solar fuels and electro fuels) are predicted to deliver essential advancements in the field of biofuels. Technology for manufacturing such solar biofuels is a rising field and is primarily based on the direct conversion of solar energy into fuel by using inexhaustible raw materials which are reasonable and easily available [2,34].



**Figure 1: Classification of transport biofuels.[33]**

Change in land use pattern is needed as first-generation biofuels can have lower GHG effluence than fossil fuels, but the reductions for most feedstocks are deficient to meet the GHG savings needed by the EU Renewable Energy Directive (RED). Yet, second-generation biofuels have, in general, a greater potential to reduce effluence, provided there is no change in land use patterns [38]. Third-generation biofuels no longer constitute a viable alternative for improvement as their GHG emissions are better than the ones from fossil fuels [1] discharge of Greenhouse gas (GHG) from transport have been amplifying at an immense rate than from any other particular sector [3]. This sector depends on fossil fuels, which is regarded for 96.3% of all transportation fuels in 2018 [4]. Transport is likewise responsible for 15% of the world's GHG effluences and 23% of general energy-associated CO2 emissions [3]. To lessen dependence on petroleum-based fuels, and to alleviate climate change, biofuels are considered promising alternative source of transportation fuels [36]. The use of biofuels has both advantages and disadvantages in various aspects such as land use pattern, region, economic value feedstock, and environmental sustainability. A lot of other factors have been studied in various research, but they cannot be considered universal due to differences in soil pattern, economic development of a place, requirement of fuel, cropland, etc.



**Figure 2: GWP of first-generation biofuels with land-use change [1,36]. ‘*A*’ refers to the number of LCA papers found in the literature and ‘*n*’ denotes the total number of analyses**

**History of biofuels**

Biofuels have been used by automotive industries ever since the discovery of the engine. For instance, the first diesel engine developed by Rudolph Diesel was also tested on peanut oil after finding out that pulverized coal was unsuitable. Until the 1940s, biofuels were widely used as viable transport fuels and bioethanol blends. As a result, Argol, Discol, and Monopolin were extensively used in the USA, Europe, and other regions [[5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7735313/#RSPA20200351C3)]. The manufacture of bioethanol gradually decreased and eventually stopped as World War broke. The Second World War led to a hike in the prices of all the necessities as most of the food supplies were being transported to the military camp for men fighting at the front, and women were left to cope with the household. As a result, the prices of food-derived fuel, in other words biofuel, also rose and fuel derived from petroleum became cheaper [36].

During the oil crisis in the 1970s, which was witnessed due to the Yom-Kippur War of 1973 and The Iranian Revolution of 1979, large number of oil supplies were disrupted, creating problems for countries that were dependent on oil exports from the war-struck regions. As a result, multiple countries have once again showed renewed interest in the production of marketable biofuels. Nevertheless, Brazil turned out to be the first country which started to produce ethanol on a huge scale as part of the National Ethanol Programme also known as ‘Proálcool’ [[6](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7735313/#RSPA20200351C4)]. Brazil began to produce anhydrous alcohol from sugarcane which was blended with upto 25% gasoline to manufacture biofuel. During the late 1990s, the prices of the crude oil rose along with concerns over national energy security. The USA and many European nations came up with policies in support of domestic biofuel industries due to rising concerns over energy exploitation [[7](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7735313/#RSPA20200351C5),36,37].

The interest in biofuel production was later rediscovered in the last decades after policies were developed to reduce the environmental harshness and strategies for the reduction of GHG effluences from the transport sector. Since then more than 60 countries have launched biofuel programs and have pledged to achieve the target of blending biofuels into their fuel pools [[8](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7735313/#RSPA20200351C6)]. The most momentous of all are Renewable Fuel Standard (RFS) [[9](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7735313/#RSPA20200351C7)] in the USA and the Renewable Energy Directive (RED) in Europe [[10](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7735313/#RSPA20200351C8),36,37].

 

**Figure 3: World fuel ethanol production, 2012-2014 [31].**

**Current scenario**

World bioethanol manufacturing has upgraded by 67%, from 67 to 110.4 billion liters, over the last decade of 2008–2018 [4]. At the same time, biodiesel production increased more than threefold, from 12 to 41 billion liters. Presently, biofuels regard for roughly 3.4% of general transportation fuels worldwide [4]. The worldwide production of biofuels is dominated by America and Brazil—generating 69% of all biofuels in 2018—followed by Europe (EU-28) with 9% [11,36]. The exclusive source of bioethanol in the USA is corn, whereas, in Brazil, sugarcane is the major source. In Europe, the primary feedstocks are corn, wheat, and sugar beet for bioethanol, while rapeseed and used cooking oil (UCO) are used for biodiesel yield [12,37].

The International Energy Agency (IEA) estimates that nearly one third of all transportation gasoline can be received from biofuels by 2050 [13]. Production of biofuels gives off several co-products, like animal feed, heat, electricity and biochemicals. Thus, before the production of biofuel of interest, it is necessary to determine the impacts of the biofuels and its co-products. The ISO 14040 and14044 standards propose that, if possible, allocation should be avoided through subdivision of processes, or by system expansion [2,36].

Contradictory results were obtained after careful observation of the LCA studies due to differences in the presumptions, data sources, allocation system and land use changes [1]. As can be observed in Figure 4,5,6, the Global Warming Potential (GWP) of first-generation bioethanol from a variety of food crops range extensively, starting from 3 to 162g CO2 eq. MJ-1. Figure 1 suggest that the common Global Warming Potential of bioethanol has decreased than that of petrol for all the feedstock (23-59 versus 94g CO2 eq. MJ-1) [36].



**Figure 4: GWP of first generation biofuel without land use change. Based on data from [**[**1**](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7735313/#RSPA20200351C24)**,36]. ‘*A*’ refers to the number of LCA articles found in the literature and ‘*n*’ denotes the total number of analyses**



**Figure 5: GWP of second-generation biodiesel. Based on data from [1] ‘*A*’ refers to the number of LCA articles found in the literature and ‘*n*’ denotes the total number of analyses**



**Figure 6: GWP of second generation of biodiesel. Based on Data from[1] ‘A’ refers to the number of LCA articles found in the literature and ‘n’ denotes the total number of analysis.**

**Table1: An overview of the number of LCA studies by biofuel type, feedstock, location, and land-use change.[1,36]**

|  | **location** | **land-use change** |  |
| --- | --- | --- | --- |
| **fuel type/feedstock** | **Europe** | **North America** | **South America** | **Asia** | **Africa** | **Australia** | **without** | **with** | **total** |
| *bioethanol—1st gen.* |
| corn | 6 | 23 | 0 | 1 | 0 | 0 | 16 | 14 | 30 |
| molasses | 4 | 12 | 0 | 25 | 3 | 4 | 30 | 18 | 48 |
| sugar beet | 19 | 1 | 0 | 0 | 1 | 0 | 14 | 7 | 21 |
| sugarcane | 0 | 4 | 32 | 1 | 1 | 0 | 28 | 10 | 38 |
| wheat | 39 | 0 | 0 | 0 | 0 | 0 | 28 | 11 | 39 |
| *bioethanol—2nd gen.* |
| bagasse | 1 | 1 | 3 | 1 | 0 | 0 | 6 | 0 | 6 |
| forest residue | 16 | 7 | 0 | 0 | 0 | 0 | 23 | 0 | 23 |
| *Miscanthus* | 14 | 9 | 0 | 0 | 0 | 0 | 16 | 7 | 23 |
| short rotation coppice | 29 | 2 | 0 | 0 | 0 | 0 | 17 | 14 | 31 |
| stover | 12 | 18 | 0 | 0 | 0 | 0 | 27 | 3 | 30 |
| straw/husk | 27 | 1 | 0 | 9 | 0 | 0 | 32 | 5 | 37 |
| switchgrass | 2 | 17 | 1 | 0 | 0 | 0 | 18 | 2 | 20 |
| *biodiesel—1st gen.* |
| palm oil | 0 | 0 | 3 | 56 | 0 | 0 | 32 | 27 | 59 |
| rapeseed | 19 | 13 | 2 | 0 | 4 | 0 | 24 | 14 | 38 |
| soya bean | 3 | 10 | 18 | 5 | 3 | 0 | 29 | 10 | 39 |
| sunflower | 1 | 0 | 2 | 0 | 5 | 0 | 5 | 3 | 8 |
| *biodiesel—2nd gen.* |
| *Camelina* | 1 | 13 | 0 | 0 | 0 | 0 | 14 | 0 | 14 |
| *Jatropha* | 0 | 0 | 7 | 8 | 7 | 0 | 18 | 4 | 22 |
| used cooking oil/tallow | 17 | 1 | 3 | 5 | 1 | 0 | 27 | 0 | 27 |
| *biodiesel—3rd gen.* |
| algae | 13 | 28 | 4 | 13 | 0 | 2 | 60 | 0 | 60 |
| total | 223 | 160 | 75 | 124 | 25 | 6 | 464 | 149 | 613 |

The huge difference in the GWP of first-generation biofuels as in Figure 1 is because of numerous reasons. For example, the LCA study on corn ethanol and soya bean biodiesel manufacturing in China discovered that the GWP of corn ethanol and soybean biodiesel were 40 and 20% higher than petrol and diesel, respectively. The study also revealed greater use of fertilizers and higher energy consumption during the manufacturing process [14]. South African sugar beet has been found to have minimal to no reduction (0–20%) in greenhouse gas emission when compare to fossil fuels. In Brazil, due to continuous growth of bioethanol the land dedicated to sugarcane cultivation has expanded [17,18]. If this results in the deforestation of tropical rainforests, the GWP of bioethanol from sugarcane can rise by almost 60% more than that of petrol [19,36].

The GWP of second-generation biofuels is significantly lower as compared to that of fossil fuels. However, there may be a massive variation among different research and feedstocks, with the values ranging from −115 to 173 g CO2 eq. MJ−1 for bioethanol and −88 to 150 g CO2 eq. MJ−1 for biodiesel [2]. The assessment of advanced biofuels is highly influenced by the uncertainties related to technologies, as these have not yet been fully implemented on commercial scale. As a result, the accuracy of the available data is not as correct as in the case of the well-mounted first-generation biofuels [36].



**Figure 7: GWP of second-generation bioethanol. Based on data from [1] ‘*A*’ refers to the number of LCA articles found in the literature and ‘*n*’ denotes the total number of analyses.**

Lignocellulosic bioethanol obtained from agricultural and forest residues has lower GWP as compared to bioethanol obtained from energy plants. This is especially due to emission of N2O emitted throughout the cultivation of energy crops, which is associated with the usage of fertilizers. The residual lignin from lignocellulosic bioethanol is expected to co-generate heat and power to satisfy the energy requirements of the process, with surplus power exported to the grid [1,36]. Similarly, in a study [20] altogether only 5% of biodiesel manufacturing yield, which could be very low as compared to more than approximately 90% taken into consideration in different studies.

A total of 27 LCA studies have estimated the GWP of third-generation algal biodiesel after using various distinct approaches, method designs, system boundaries, methodologies, and assumptions for feedstocks, nutrient, and co-product management. These differences in the available choices have resulted in values ranging from −2400 to 2880 g CO2 eq. MJ−1. This implies that emission of GHG can either reduce or increase significantly by microalgal fuel, compared to regular diesel, depending on the assumptions. Nevertheless, most of the studies emphasizes that at the current state of developmental, algal biodiesel has better lifecycle compared to fossil diesel. The principal reason for increased emissions is the result of decreased algal yield and increased usage of energy during the stages of cultivation, harvesting, and drying [25,26,27,28,29,36]. Some research studies claim that the amount of greenhouse gas savings from using of GHG instead of diesel is significantly higher, is based on the best-case assumptions that would not be viable for large-scale adoption. These include utilization of CO2 derived from cement factories as a raw material [21], cane sugar as a nutrient/feedstock [22], and reutilization of necessary nutrients obtained from anaerobic digestion plants [24] or wastewater [23,36].

**Future scopes**

Reducing GHG emissions, energy conservation, and rural improvement are important factors that influence the global adoption of biofuels. However, increasing the production of biofuels is a significant issue of concern [37]. Hike in food prices, risk of increasing GHG emissions due to land-use change (LUC)and deterioration of land, forest, water resources, and ecosystems pose a significant concern [30]. The cultivation of feedstock has entered a competition as agricultural land has been diverted from food-producing land to being used as fuel-producing land, thereby raising concerns about food security. The increasing requirement for food and other agricultural goods has led to increased chances of deforestation and the utilization of land rich in biodiversity. This has also resulted in the consumption of significant amount of freshwater, fertilizers, and pesticides, leaving negative consequences on the environment. The primary focus of most LCA studies on biofuels involve examination of GHG emission and the preservation of fossil fuel resources. the conservation of fossil fuels are the centres of interest in maximum LCA research on biofuels. Additional categories of environmental impacts considered in biofuel LCA research consist of acidification, eutrophication, photochemical smog, human toxicity, and eco-toxicity [1,36].

The utilization of the newly discovered information and advancement in technologies, called “synthetic biology”, enables the creation of biological systems. Shortly, this will enable the direct conversion of solar energy into fuel from inexhaustible raw materials (e.g.: sunlight, water, and CO2). Production of such solar biofuels are anticipated to occur in genetically engineered photosynthetic microorganisms or artificial dwelling factories. The upcoming photobiological solar fuel production system intends to employ photosynthetic microorganisms as “catalysts” to harvest solar energy and produce great amount of high-quality fuel [34].Unlike present methods which involve the production of fuel based on harvested biomass, in the future microorganisms will be tailored to secrete the fuel for continuous collection in a photo-bioreactor ensuring simultaneous production and collection of the fuel [2].

Biggest scientific discovery of microbes that are involved in the natural breakdown of lignin to give easy access to cellulose. Cellulose is a naturally occurring fibre found in the cell wall of plants; its function is to keep the cells together [34]. To convert it into a usable form, this first needs to be broken down into sugar, which is later converted to ethanol after fermentation or other liquids that could be used to produce fuel or bioethanol. Currently, this conversion of cellulose into sugar is being carried out using expensive enzymes. This ultimately leads to an urgent requirement for the development of tailored microbes that can ferment cellulose into sugar, thereby cutting the cost of expensive enzymes and making the process more economical.

**Conclusion**

Biofuels have emerged as a potential alternative to conventional fossil fuels, aiming to reduce greenhouse gas emissions and reduce the impacts of climate change. With concerns over energy demand, security, and the need to reduce CO2 emissions from fossil fuels, biofuels have gained attention as a promising solution for addressing these challenges. However, it is important to consider the potential resource and environmental impacts associated with biofuel production.

Despite having the potential in terms of reducing greenhouse gas emissions and reducing dependence on fossil fuels, there are also concerns regarding the negative environmental impact of biofuels.

The production of biofuels requires the cultivation of biomass crops, which can lead to land use changes and potential habitat destruction, which have negative implications for biodiversity and ecological balance. Additionally, the production of biofuels requires significant amounts of water and energy, which can contribute to resource depletion and increase environmental pressures. Furthermore, the use of certain feedstocks for biofuel production, such as corn, sugarcane, soybeans, etc., can contribute to deforestation and loss of agricultural land. These concerns highlight the need for careful planning and sustainable practices in biofuel production to minimize environmental impacts. In conclusion, biofuels have the potential to play a crucial role in reducing greenhouse gas emissions and addressing energy challenges. However, it is essential to carefully assess and manage the environmental impacts associated with biofuel production. Considering the potential environmental impacts associated with biofuel production, it is crucial to carefully assess and manage the sustainability of these alternative fuels. To ensure the long-term viability of biofuels as a sustainable and environmentally friendly energy source, it is important to prioritize the use of feedstocks that have minimal impacts on land use, water resources, and biodiversity. In addition, certification schemes can be an effective approach to ensure that biofuels are produced sustainably, adhering to certain environmental and social standards. These schemes can help mitigate the negative environmental impacts of biofuel production by setting standards and guidelines for sustainable practices. Furthermore, the implementation of certification schemes can assure consumers and stakeholders that biofuels are being produced with minimal environmental impact. In general, although biofuels can potentially reduce greenhouse gas emissions and dependence on fossil fuels, there are concerns regarding their impact on the environmental. These concerns must be addressed through sustainable practices, careful land use planning, and the implementation of certification schemes. In conclusion, biofuels have the potential to be a possible substitute for fossil fuels in terms of decreasing greenhouse gas emissions and tackling energy issues. Nevertheless, it is crucial to overlook the environmental consequences associated with the production of biofuel in order to guarantee their sustainability in the future.

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