**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're typically referred to as first, second, and third-generation biofuels (according to the EASAC report 2012), while the fourth-generation biofuels are just emerging at the basic research level. On the way toward a sustainable economy, the development of efficient biofuel production strategies based on solar energy is of immense importance. Most of the primary-era biofuels are received from crops as energy-containing molecules like sugars, oils, and cellulose [34]. They yield very less biofuel and hurt food security. Since first-era biofuels are produced through well-installed technology and processes, such as fermentation, distillation, and transesterification, they're normally mentioned as ‘traditional/conventional biofuels' [36]. Efforts are required 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 numerous transport sectors for bringing down the costs (EASAC 2012). The second-generation biofuels are an improvement in producing biofuels from a feedstock of lignocellulosic, non-food materials that include straw, bagasse, forest residues, and crops on marginal lands. Projects are required to increase the amount of renewable carbon and hydrogen that can be converted to fuels from “second generation” biomass. The 3rd generation technology biofuels are primarily based on algal biomass production [34]. Biodiesel obtained from microalgae through traditional transesterification or hydro-remedy of algal oil is typically called 3rd generation biofuel. Second- and third-technology biofuels are often cited as ‘superior biofuels’ [36]. Currently, they are under extensive research to improve both the metabolic production of fuels and the Separation procedures in bio-oil manufacturing to remove non-fuel components and thereby decrease manufacturing costs. The fourth-generation biofuels (i.e. Photobiological solar fuels and electrofuels) are predicted to deliver essential breakthroughs 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 required as first-generation biofuels can have lower GHG emissions than fossil fuels, but the reductions for most feedstocks are insufficient to meet the GHG savings required by the EU Renewable Energy Directive (RED). However, second-generation biofuels have, in general, a greater potential to reduce emissions, 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] Emissions of Greenhouse gas (GHG) from transport have been increasing at an immense rate than from any other known sector [3]. This sector depends on fossil fuels, which accounted for 96.3% of all transportation fuels in 2018 [4]. Transport is equally responsible for 15% of the world's GHG emissions and 23% of general energy-associated CO2 emissions [3]. To lessen dependence on petroleum-based fuels, and to mitigate climate change, biofuels are considered promising alternative 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 articles 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, Agrol, Discol, and Monopolin were commonly 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 petroleum-derived fuel 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, many countries once again showed renewed interest in the production of commercial biofuels. However, Brazil became 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 further rediscovered in the past decade after policies were developed to reduce the environmental severity and strategies for the reduction of GHG emissions 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 improved 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. Currently, biofuels account for approximately 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 production [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, such as animal feed, heat, electricity and biochemicals. Therefore, 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 assumptions, data sources, allocation method and land use changes [1]. As can be observed in Figure 4,5,6, the Global Warming Potential (GWP) of first-generation bioethanol from various food crops range considerably, 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, also higher use of fertilizers, higher process energy consumption was observed [14]. Low or no GHG savings (0–20%) in comparison to fossil fuels have been reported in the case of South African sugar beet. The increasing demand for bioethanol from sugarcane in Brazil has led to a continuous expansion of land to be used for the cultivation of sugarcane [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 notably decreased than 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 uncertainties related to technologies play a significant role in the assessment of advanced biofuels as these have not been fully commercialized. Therefore, the quality of the available data isn't 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 from agricultural and forest residues has a decreased GWP than bioethanol from energy plants This is largely because of N2O emitted throughout the cultivation of energy crops, associated with the usage of fertilizers. The residual lignin in the case of lignocellulosic bioethanol is assumed 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.

 In total, 27 LCA studies have estimated the GWP of third-generation algal biodiesel using numerous distinct approaches, method designs, system boundaries, methodologies, and assumptions for feedstocks, nutrient, and co-product management. As a result of the variation in those options, the GWP differs extensively among the studies, ranging from −2400 to 2880 g CO2 eq. MJ−1. This suggests that microalgae diesel can either reduce or increase GHG emissions significantly, relative to diesel, depending on the assumptions. However, a majority of the research emphasizes that during the current developmental state, algal biodiesel has better lifestyles cycle GHG emissions than fossil diesel. The principal motives for higher emissions consist of decreased algal yield and increased energy for cultivation, harvesting, and drying stages [25,26,27,28,29,36]. Some research that suggested the excessive savings of GHG in comparison to diesel is primarily based on the best-case assumptions that would not be viable for large-scale implementation. These consist of the usage of CO2 from cement plants as a feedstock [21], cane sugar as a nutrient/feedstock [22], and recycling of required nutrients from anaerobic digestion plants [24] or wastewater [23,36].

**Future scopes**

On one hand, reduced GHG emissions, energy conservation, and rural improvement are the crucial promoters of biofuels globally, on the other hand, increasing the production of biofuels is a major matter of concern [37]. Hike in food prices, risk of increasing GHG emissions through land-use change (LUC) resulting from the production of biofuel feedstocks, and degradation of land, forests, water resources, and ecosystems as a whole [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 growing demand for agricultural products has increased the risk of deforestation and the use of land rich in biodiversity to meet this demand, along with the associated usage of freshwater, fertilizers, and pesticides, leaving negative consequences on the environment. GHG emissions and the conservation of fossil fuels are the centers of interest in maximum LCA research on biofuels. Other environmental effect classes taken into consideration in biofuel LCA research consist of acidification, eutrophication, photochemical smog, human toxicity, and eco-toxicity [1,36].

The utilization of the discovered knowledge and new technologies, called “synthetic biology”, makes the engineering of biological systems possible. Shortly t, this will enable the conversion of solar energy directly to fuel from inexhaustible raw materials (e.g.: sunlight, water, and CO2). Such solar biofuels are anticipated to be produced in engineered photosynthetic microorganisms or artificial dwelling factories. The future photobiological solar fuel production system aims at using photosynthetic microorganisms as “catalysts” to harvest solar energy for the direct production of an increased rate 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.

While biofuels have the potential to reduce greenhouse gas emissions and dependence on fossil fuels, there are also concerns about their environmental impact.

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. Overall, while biofuels have the potential to reduce greenhouse gas emissions and dependence on fossil fuels, there are significant concerns about their environmental impact. 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 viable alternative to fossil fuels in terms of reducing greenhouse gas emissions and addressing energy challenges. However, the environmental impacts of biofuel production must be carefully managed to ensure their long-term sustainability.

In conclusion, biofuels have the potential to be a viable alternative to fossil fuels in terms of reducing greenhouse gas emissions and addressing energy challenges. However, their environmental impact must be carefully managed to ensure sustainable production and minimize negative effects on land use, water resources, and biodiversity.

**Reference**

1. Harish K. Jeswani, Andrew Chilvers, Adisa Azapagic, 2020, Environmental sustainability of biofuels; a review, Proceedings of Royal Society A; Mathematical, Physical and Engineering Sciences
2. [Eva-Mari Aro](https://pubmed.ncbi.nlm.nih.gov/?term=Aro%20EM%5BAuthor%5D), From first-generation biofuels to advanced solar biofuels. [Ambio.](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4678123/) 45(Suppl 1): 24–31.
3. Sims R. et al 2014. Transport. In Climate Change 2014: mitigation of climate change contribution of working group III to the fifth assessment report of the intergovernmental panel on Climate change (eds Edenhofer O, et al.). Cambridge, UK: and New York, NY: Cambridge University Press
4. IEA. 2019. Renewables 2019. Paris: See <https://www.iea.org/reports/renewables-2019>.
5. Michael K, Steffi N, Peter D. 2011. The past, present, and future of biofuels—biobutanol as promising alternative. In Biofuel production—recent developments and prospects (ed. dos Santos MA.), pp. 451–486. Rijeka, Croatia: InTech.
6. Soccol CR, Vandenberghe LPS, Costa B, Woiciechowski AL, de Carvalho JC, Medeiros ABP, Francisco AM, Bonomi LJ. 2005. Brazilian biofuel program: an overview. J. Sci. Ind. Res. 64, 897–904.
7. Food and Agriculture Organization (FAO). 2013. Biofuels and the sustainability challenge: a global assessment of sustainability issues, trends and policies for biofuels and related feedstocks. Rome, Italy: Food and Agriculture Organization of the United Nations.
8. International Renewable Energy Agency (IRENA). 2016. Innovation outlook: advanced liquid biofuels. Abu Dhabi, United Arab Emirates: International Renewable Energy Agency.
9. EPA. 2010. Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis (EPA-420-R-10-006). U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division See [www.epa.gov/otaq/fuels/renewablefuels/regulations.htm](https://www.epa.gov/otaq/fuels/renewablefuels/regulations.htm)
10. European Commission. 2018. Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. Brussels, Belgium: Official Journal of the European Union.
11. Renewable Energy Policy Network for the 21st Century (REN21). 2019. Renewables 2019—Global status report See ...
12. OECD/FAO. 2019. OECD-FAO agricultural outlook 2019–2028. Paris, France: OECD Publishing.
13. IEA. 2011. Technology roadmap: biofuels for transport. Paris, France: International Energy Agency.
14. Ou X, Zhang X, Chang S, Guo Q. 2009. Energy consumption and GHG emissions of six biofuel pathways by LCA in (the) People's Republic of China. Appl. Energy. 86, S197–S208. (10.1016/j.apenergy.2009.04.045) - [DOI](https://doi.org/10.1016/j.apenergy.2009.04.045)
15. Stephenson AL, von Blottnitz H, Brent AC, Dennis JS, Scott SA. 2010. Global warming potential and fossil-energy requirements of biodiesel production scenarios in South Africa. Energy Fuels 24, 2489–2499. (10.1021/ef100051g) - [DOI](https://doi.org/10.1021/ef100051g)
16. Tomaschek J, Oezdemir ED, Fahl U, Eltrop L. 2012. Greenhouse gas emissions and abatement costs of biofuel production in South Africa. Global Change Biol. Bioenergy 4, 799–810. (10.1111/j.1757-1707.2011.01154.x) - [DOI](https://doi.org/10.1111/j.1757-1707.2011.01154.x)
17. Mello FFC, et al. 2014. Payback time for soil carbon and sugarcane ethanol. Nat. Clim. Change 4, 605–609. (10.1038/nclimate2239) - [DOI](https://doi.org/10.1038/nclimate2239)
18. Lisboa CC, Butterbach-Bahl K, Mauder M, Kiese R. 2011. Bioethanol production from sugarcane and emissions of greenhouse gases—known and unknowns. Global Change Biol. Bioenergy 3, 277–292. (10.1111/j.1757-1707.2011.01095.x) - [DOI](https://doi.org/10.1111/j.1757-1707.2011.01095.x)
19. García CA, Fuentes A, Hennecke A, Riegelhaupt E, Manzini F, Masera O. 2011. Life-cycle greenhouse gas emissions and energy balances of sugarcane ethanol production in Mexico. Appl. Energy. 88, 2088–2097. (10.1016/j.apenergy.2010.12.072) - [DOI](https://doi.org/10.1016/j.apenergy.2010.12.072)
20. Ou X, Zhang X, Chang S, Guo Q. 2009. Energy consumption and GHG emissions of six biofuel pathways by LCA in (the) People's Republic of China. Appl. Energy. 86, S197–S208. (10.1016/j.apenergy.2009.04.045) - [DOI](https://doi.org/10.1016/j.apenergy.2009.04.045)
21. Singh A, Olsen SI. 2013. Comparison of algal biodiesel production pathways using life cycle assessment tool. In Life cycle assessment of renewable energy sources (eds Singh A, Pant D, Olsen SI), pp. 145–168. London, UK: Springer.
22. Orfield ND, Levine RB, Keoleian GA, Miller SA, Savage PE. 2015. Growing algae for biodiesel on direct sunlight or sugars: a comparative life cycle assessment. ACS Sustain. Chem. Eng. 3, 386–395. (10.1021/sc5004117) - [DOI](https://doi.org/10.1021/sc5004117)
23. Mu D, Min M, Krohn B, Mullins KA, Ruan R, Hill J. 2014. Life cycle environmental impacts of wastewater-based algal biofuels. Environ. Sci. Technol. 48, 11 696–11 704. (10.1021/es5027689) - [DOI](https://doi.org/10.1021/es5027689)- [PubMed](https://pubmed.ncbi.nlm.nih.gov/25220843/)
24. Chowdhury R, Freire F. 2015. Bioenergy production from algae using dairy manure as a nutrient source: life cycle energy and greenhouse gas emission analysis. Appl. Energy. 154, 1112–1121. (10.1016/j.apenergy.2015.05.045) - [DOI](https://doi.org/10.1016/j.apenergy.2015.05.045)
25. Passell H, et al. 2013. Algae biodiesel life cycle assessment using current commercial data. J. Environ. Manage. 129, 103–111. (10.1016/j.jenvman.2013.06.055) - [DOI](https://doi.org/10.1016/j.jenvman.2013.06.055)- [PubMed](https://pubmed.ncbi.nlm.nih.gov/23900083/)
26. Tonini D, Hamelin L, Alvarado-Morales M, Astrup TF. 2015. GHG emission factors for bioelectricity, biomethane, and bioethanol quantified for 24 biomass substrates with consequential life-cycle assessment. Bioresour. Technol. 208, 123–133. (10.1016/j.biortech.2016.02.052) - [DOI](https://doi.org/10.1016/j.biortech.2016.02.052)- [PubMed](https://pubmed.ncbi.nlm.nih.gov/26938807/)
27. Pragya N, Pandey KK. 2016. Life cycle assessment of green diesel production from microalgae. Renew. Energy 86, 623–632. (10.1016/j.renene.2015.08.064) - [DOI](https://doi.org/10.1016/j.renene.2015.08.064)
28. Yuan J, Kendall A, Zhang Y. 2015. Mass balance and life cycle assessment of biodiesel from microalgae incorporated with nutrient recycling options and technology uncertainties. Global Change Biol. Bioenergy. 7, 1245–1259. (10.1111/Gibb.12229) - [DOI](https://doi.org/10.1111/gcbb.12229)
29. Soratana K, Harper WF Jr, Landis AE. 2012. Microalgal biodiesel and the renewable fuel standard's greenhouse gas requirement. Energy Policy 46, 498–510. (10.1016/j.enpol.2012.04.016) - [DOI](https://doi.org/10.1016/j.enpol.2012.04.016)
30. UNEP. 2009. Towards sustainable production and use of resources: assessing biofuels. United Nations Environment Programme; See <https://www.resourcepanel.org/file/560/download?token=04PkF6fe>
31. OECD/FAO. *Agricultural Outlook.* 2015. <http://dx.doi.org/10.1787/data-00736-en> Available online: [[Google Scholar](https://scholar.google.com/scholar_lookup?title=Agricultural+Outlook&publication_year=2015&)]
32. Ashworth, K., Folberth, G. A., Hewitt, C. N., & Wild, O. 2012. Impacts of near-future cultivation of biofuel feedstocks on atmospheric composition and local air quality. <https://scite.ai/reports/10.5194/acp-12-919-2012>
33. Love J. 2022. Microbial pathways for advanced biofuel production. Biochem Soc Trans. 2022 Apr 29;50(2):987-1001. doi 10.1042/BST20210764. PMID: 35411379; PMCID: PMC9162456.
34. Link.springer.com
35. [www.newsadesso.info](http://www.newsadesso.info)
36. [www.ncbi.nlm.nih.gov](http://www.ncbi.nlm.nih.gov)
37. pubmed.ncbi.nlm.nih.gov