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Navigating the Aspects of Greener Future and Sustainability Through Biodiesel

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Abstract: Fossil fuels are increasingly used to fulfill the energy requirements. The rapid population rise has increased fuel and energy demand. These fossil fuels are limited and cause harmful emissions that cause critical diseases. Moreover, the effects of climate change and global warming are affecting everyone. This situation calls for switching to alternative fuels that would effectively reduce the usage of fossil fuels and their negative environmental impacts. Biodiesel is one of the renewable fuels that is gaining popularity due to its non-polluting and environment-friendly nature. The demand for biodiesel is increasing and is considered a promising alternative and safer energy source. The market size for biodiesel is expected to increase rapidly by 2030. This paper will try to study the current market trends for biodiesel, its reasons, and how it will serve as an enabler in achieving sustainability and a cleaner environment.

***Keywords*—Biodiesel, Environment, Sustainability, Emissions, Fossil fuels.**

1. Introduction: Renewable fuels are gaining importance due to their ability to obtain a sustainable and green future. These fuels are envisioned as an alternative to fossil fuels as they can play a pivotal role in reducing greenhouse gas emissions and encouraging environmental sustainability. It is well known that fossil fuels are the major contributors to global energy requirements. Though fossil fuels are used widely, their negative impacts on the environment like harmful emissions, climate change, air pollution, etc., can never be ruled out.

Many European countries depend on fossil fuels for fulfilling their major energy requirements. Researchers and Governments predict that by 2050, these countries will be left with only fourteen percent of oil reserves, eighteen percent of gas reserves, and seventy percent of coal. The large-scale use of these fossil fuels poses a great concern about their depletion in the coming years. These fossil fuels or non-renewable energy sources may be exhausted and unavailable for future generations [1]. Besides the depletion, the contribution of fossil fuels in increasing greenhouse gas emissions is another concern that needs immediate attention. In many countries, fossil fuels are fulfilling the growing energy demands driven by the fast population growth and technological developments in various sectors [2]. However, countries with sufficient reserves should not neglect the worsening of climate change caused by fossil fuels and should search for alternative solutions to meet the fuel requirements [3]. Moreover, the heavy dependency on fossil fuels has resulted in ecological disruption. Fossil fuels are the creators of nearly seventy-five percent of the carbon dioxide emissions after World War II. This calls for the urgent need for policy reformations to reduce reliance on fossil fuels [4]. Fossil fuel combustion releases nitrogen dioxide and other harmful pollutants into the environment causing a detrimental effect on food security and

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agricultural production. Moreover, the hazardous chemical constituents pose significant health risks [5]. There is a direct correlation between the usage of fossil fuels and carbon dioxide emissions [6]. Fossil fuel usage results in ecological degradation due to the depletion of natural resources. The deterioration of the environmental quality and manipulation of the Sulphur cycle need urgent attention to tackle the unanticipated ecological consequences [7]. The irregularities in the climate like hot weather, off-season rains, and floods are consequences of the condensation of greenhouse gases into the atmosphere. The transport sector is a major contributor to the carbon dioxide emissions [8]. Burning diesel and petrol releases carbon dioxide and other greenhouse gases like methane and nitrous oxide. In the USA there was a steep increase in greenhouse gas emissions between 1990 and 2022, due to transportation and it was nearly twenty-eight percent of the total emissions [9].

Fossil fuels are non-renewable; they need millions of years to be formed again once they are used. The speed with which fossil fuels are deployed globally poses a great concern in meeting the energy and fuel requirements in the coming years. In response to the negative consequences of fossil fuels, biofuels are seen as an alternative to meet energy requirements. With increased urbanization and globalization, transportation will increase in the coming years. Fossil fuels will get depleted due to their high usage. Moreover, the negative impacts on the environment cannot be ruled out. This indicates the necessity to research renewable fuels to meet energy demands without fearing depletion and negatively impacting the environment.

Despite the available information on fossil fuels, there are knowledge gaps on their long-term impacts on people's health. Moreover, there are gaps in whether alternative sources or renewable fuels will be able to meet the energy demands without deteriorating the environment. Secondly, transitioning from fossil fuels to renewable fuels requires a deeper exploration. Along with the environmental impacts, there should be a comprehensive study on socio-impacts of transition. As the world grapples with climate change and thinks of sustainable energy solutions, it is crucial to understand the multifaceted implications of fossil fuels. Addressing the research gaps will not only help to find solutions but will help to improve our understanding of these issues and frame effective policy measures. These policies will be crucial in reducing dependence on fossil fuels, promoting sustainable energy practices, and reducing the gap between the challenges faced by the developed and the developing nations for transition toward renewable fuels.

The two renewable fuels used in recent years are biodiesel and green diesel. The objectives of this paper are i) Studying biodiesel production and its application ii) To study how biodiesel helps achieve sustainability and iii) To know the market dynamics and trends of biodiesel.

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2. Biodiesel Production

Biodiesel has emerged as an alternative fuel due to its potential to reduce greenhouse gas emissions. Its production involves using vegetable oils, animal fats, and waste materials passed through chemical processes.

One of the widely used methods for producing biodiesel is transesterification. It uses short-chain alcohols like methanol or ethanol to convert triglycerides of oils to simple alkyl esters. The different types of catalysts used in this process are homogeneous and heterogeneous. These catalysts facilitate the effective transformation of bio-based reactants [10]. One more method called microwave processing gives improved biodiesel yield by reducing the reaction times compared to the traditional methods [11]. Feedstocks like edible, nonedible oils, animal fat, etc. can be used to derive biodiesel. These feedstocks serve dual benefits by being a source of renewable fuels and supporting waste management [12].

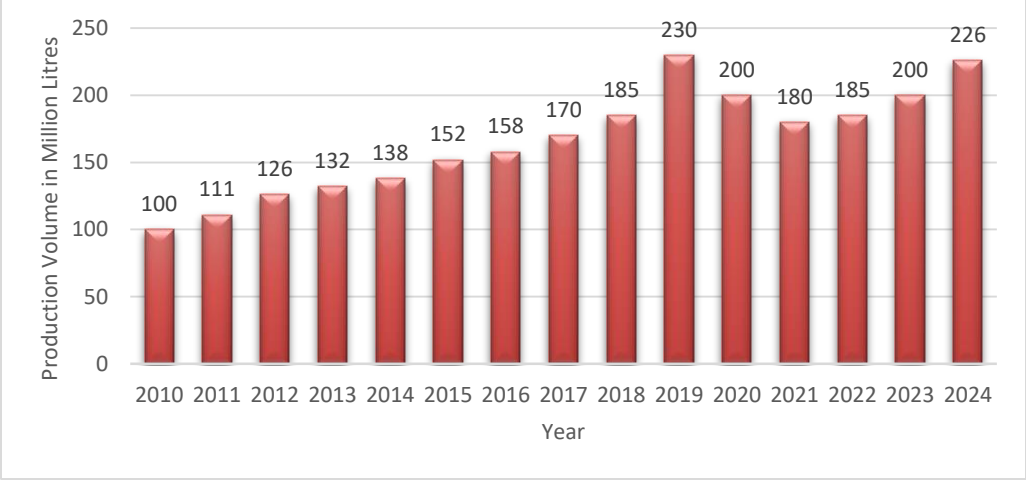

Fig 1. Production Trends of Biodiesel in India Million Liters [13]

Biodiesel production is increasing globally. As indicated in Fig. 1., the production volume in a million liters was 100 in 2010 which rose gradually to 200 in 2023; in 2024 it is predicted to be around 226. The increase in biodiesel production indicates that the demand for its usage is increasing and the realization of switching to renewable or biofuels is taking pace [13]. The biodiesel production process shown in Fig 2. includes the following steps: Collected Oil, Pretreatment, Esterification, Transesterification, Atmospheric Distillation, Washing and Drying, Biodiesel, and Fuel Analysis. Biodiesel can be used in transportation and industrial sectors. It can be used in cars, buses, etc. for road transport. At the same time, it can be used for rail transport and aviation. Biodiesel can offer eco-friendly alternatives to industrial machinery and equipment, and some of its applications are mentioned in Table 1 [14].

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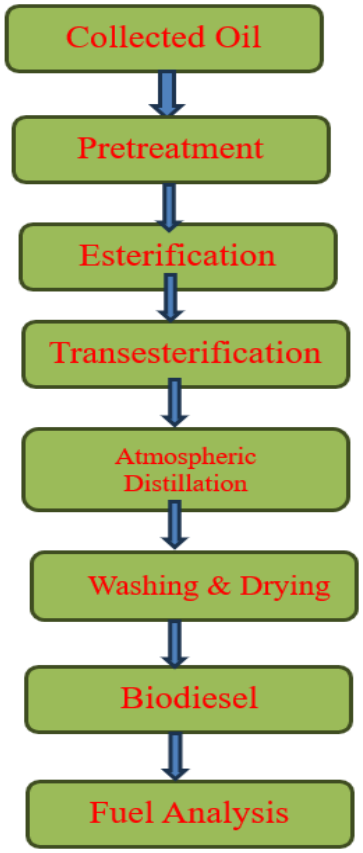

Application	Description
Construction	Power heavy machinery and reducing emissions on construction sites
Agriculture	Used for tractors and farm equipment, promote sustainable farming practices
Generator	Stable power backup with reduced emissions
Mining	Reduce environmental impacts of mining practices, especially in the remote regions
Manufacturing	Heating system and industrial machinery for constant energy
Shipping & Marine	Fuel for ships and reduce emissions in marine transportation
Material Handling	Used in forklifts and warehouse machines and improve indoor air quality
Waste Management	Powering waste-collection trucks and decreasing pollution in urban areas
Railway Locomotives	Fuels for trains to have eco-friendly rail transportation
Oil and Gas	Powering industrial equipment to reduce the carbon footprint of various processes in the industry

Fig. 2. Biodiesel Production Process [14] Table 1: Biodiesel's application and environment friendliness [14]

3. Biodiesel Market Trends

The biodiesel market size tends to grow due to its popularity as a green and renewable fuel. As the world is concerned about climate change and sustainability, everyone has started looking for options to replace fossil fuels.

The market size for biodiesel was valued at USD 32.09 billion in 2021 and was anticipated to grow at a compound annual growth rate (CAGR) of 10% from 2022-2030 [23]. It was prized at USD 40 billion in 2022 and was predicted to be around USD 42.69 billion in 2023 and found to grow by 5.25% during 2024-2031 [24]. Another report by Precedence Research has estimated the biodiesel market size to be USD 36.48 billion in 20222 and that it would grow at a CAGR of 8.1% to reach USD 79.12 billion in 2032 [25]. Vantage market research indicates that the revenue for the biodiesel sector was USD 39.29 billion and 2022 and it will grow at a CAGR of 3.4% to reach USD 51.35 billion in 2030. Biodiesel is the only renewable fuel approved by the Environmental Protection Agency (EPA) [30]. Although these reports may show slight variations in their present

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and future market size, they commonly indicate the growth of the use of biodiesel, market trends, growth factors, and challenges. They provide a deep-dive analysis of the global scenario.

The key reasons for the increase in demand for biodiesel are i) Less GHG emissions ii) Compatibility with the existing diesel engines iii) Increase in demand for vehicles due to increasing population iv) Increase in the number of Industries v) Growing preference for renewable and biodegradable fuels. Many developing nations intend to replace fossil fuels in the transportation sector by 10-20% in the coming years [23]. Europe is expected to emerge as a primary market for the biodiesel. A report issued in 2020 by the National Biodiesel Board reveals that utilization of biodiesel will cross six billion gallons for applications like power generation, civil aviation, etc., and fifteen billion gallons by 2025. The biodiesel market will expand, and GHG and carbon dioxide emissions will be reduced by 35 million metric tons annually. Vegetable oil is a frequently used feedstock for biodiesel. The expenses for feedstock may sometimes be nearly 80-85% of the total production cost. Expensive feedstock will reduce profits and hinder achieving financial stability in the long term [25]. The demand for biodiesel started declining during the pandemic due to reduced transportation but it started recovering robustly post-pandemic. The global energy market is trying to comply with the Paris Agreement by adopting sustainable energy sources. Though conventional fuels are available at cheaper rates, the urge to reduce emissions remains a significant factor behind the global adoption of biodiesel [24].

The cost of biodiesel production is governed by factors like raw materials, volumes of production, and geographical location. The International Energy Agency (IEA) has observed fluctuations in biodiesel prices in Europe. The production cost of biodiesel depends on the kind of feedstock and may range around USD 0.53 to USD 11.13 per gallon for feedstocks like palm oil, soybean oils, etc. However, another point worth noting is that biodiesel production costs may be slightly higher than in conventional diesel in some cases [26]. One of the reasons for the increased production cost is the inefficient practices used by the plants. Another factor that affects the production cost is the low quality of feedstock material [27]. The number of production plants should be increased. It will increase overall production and decrease capital and operating costs. Similarly, there should be a revision of financing rates and terms for these plants and technological advancements should be adopted. The feedstock costs are a very important factor in the overall production costs. There should be more research on the different types of feedstocks, and any new materials that can be used as feedstock, and decide a strategy for buying feedstock after predicting their prices, demand, and trends. Policy regulations and incentives would significantly help to improve production capacities and make the fuel more cost-effective [28]. However, the depletion of conventional energy sources and environmental concerns have forced researchers to find replacements and develop better avenues for improving production in the biodiesel sector. The demand-supply gap will open doors for new competitors. It will foster collaboration and partnerships at a global level to increase biodiesel and fulfill the demands of people and industries. Though sometimes the

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production cost of biodiesel may concern many, the lower emissions and environmental friendliness will drive the marker potential for biodiesel. The Governments can support this by imposing limits on emissions and the usage of fossil fuels [25].

The global biodiesel market can be studied based on three types of insights feedstock, application, and regional. The feedstock segment can be categorized into vegetable oils and animal fats. The different vegetable oils used are palm, soybean, corn, etc. The vegetable oil section had 96.4% of global revenue in 2022 [25]. Vegetable oil accounted for 97% of the global revenue during 2021. The raw material selection in a region depends on the availability of the feedstock and its cost. Palm oil is the major used feedstock in Indonesia, Thailand, Germany, France, and Colombia. A large portion of the biodiesel production in Indonesia and Thailand, nearly 80% was done using palm oil. European nations rely on these Asian countries to import feedstocks [23].

Based on application the biodiesel market is divided into automotive, aviation, power generation, and others. The automotive segment dominates the biodiesel market with around two-fifths of the market share. The higher cetane number in biodiesel causes better ignition and combustion. This has led to increased use of biodiesel blends by automotive engine manufacturers. Its environmental benefits and compatibility with the existing heating systems have increased usage in residential heating and provide better indoor air quality. Military and industrial heating are other segments that are gaining interest [26]. Its' application in the marine industry is expected to grow due to its biodegradable nature. Moreover, it is non-toxic and free from Sulphur and aromatics. The usage of biodiesel is increasing in the agriculture sector due to increased mechanization. The power generation sector is predicted to support using biodiesel in the future. Furthermore, as Governments across the world are supporting to increase in the usage of renewable fuels, the market of biodiesel will certainly keep on growing significantly between 2023 and 2032 [23].

The region-wise segmentation of the global market for biodiesel indicates that the European region captured the largest market share of nearly 48% in 2022 [25] and 46.7% in 2021 [23]. In 2022, Asia Pacific accounted for 25%, North America 21%, Latin America 4%, and Middle East & Africa 2% of the biodiesel market share. The earlier adoption of biodiesel is a primary reason for the largest market share of European nations. Moreover, the Government's focus on reducing carbon emissions and switching to renewable fuels is a significant factor in increasing the demand in the European regions. One of the European nations, Germany has been the largest feedstock producer and has contributed to increasing the demand for biodiesel in the region [25]. Though Europe was the largest biodiesel market in 2022, the Asia Pacific region will emerge as the fastest-growing market in the coming years [30]. Lower interest rates for raw materials will increase biodiesel consumption and support overall market growth from 2022 to 2030. Thailand is predicted to emerge as one of the fastest-growing markets, due to the increase in demand for diesel-powered engines. Malaysia and Indonesia produce nearly 90% of the palm oil and are therefore expected to provide better opportunities for biodiesel production. However, using palm oil in the food industry

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may hamper its supply as a raw material and negatively affect market growth [23]. Furthermore, it is anticipated that the Indian Government will blend more than 5% biodiesel, between 2023 and 2032. South and Central America produced 10960.1 million liters of biodiesel in 2022 to meet the increasing demands for domestic consumption [25].

The study of the biodiesel market can be segmented based on blends and production technology. It is segmented into B100, B20, B10, and B5. The commonly used blends are B5 and B20. These blends produce a better equilibrium of price, emissions, solvent ability, compatibility, and performance. In 2021, B5 grabbed the biggest market share. Maximum customers prefer buying B20 and their lower blends from the market. ASTM has permitted using B20 and B5 in compression-ignition engines. These engines were designed to run on petroleum diesel and were used in generators, cars, trucks, tractors, etc. The decrease in emissions is approximately proportional to the blend level. For instance, the B20 blend will show a nearly 20% reduction in the emissions. The production technologies used for segmenting the biodiesel market are Pyrolysis, Trans-Esterification, and others [30].

Besides the higher production costs some of the challenges faced by the biodiesel sector are [29]:

i. Collecting raw materials and their transportation to the plants will add to the production costs.
ii. Standardization and compatibility issues may arise due to the inconsistent quality of oils produced from different types of plants.
iii. Biodiesel is slightly more expensive than fossil fuels and questions its economic viability.
iv. Lack of policies and regulatory support will prevent the expansion of the biodiesel market.
v. The cost of feedstock pretreatment will directly impact a large portion of production cost.
vi. Carbon dioxide released during production is an important factor to be considered to ensure its effective utilization and minimize the environmental risks caused by emissions.
vii. Unavailability of suitable land for cultivation, will increase cultivation costs, Moreover, a shortage of seeds and low productivity will impose more challenges.

4. Achieving Sustainability with Biodiesel

Sustainability is a growing issue in all sectors. Energy availability and sustainability aspects are interdependent. The sustainability paradigm mainly relies on three aspects: environment, society, and economy [15]. The production of biodiesel is considered sustainable due to the reduction in

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negative impacts on the environment and society. It is, therefore, emerging as a low-carbon substitute for regularly used fossil fuels. [16].

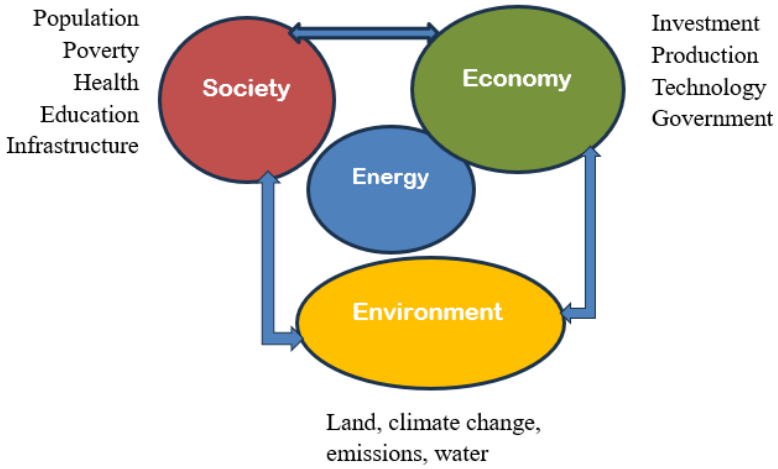

Fig 3. The Interrelationship between energy availability and sustainability [15].

The sustainability paradigm can be linked to biodiesel due to several benefits:

i. Reduction in GHG emissions: Biodiesel is produced from biomass and therefore helps reduce GHG emissions compared to non-renewable fuels. Transportation, one of the largest factors for increased GHG emissions, can contribute to decreased emissions using biodiesel. Moreover, having biodiesel as an alternative fuel will reduce dependency on fossil fuels. The availability of alternate fuels or substitutes will improve energy security and prevent price fluctuations in global oil prices [17].

ii. Economic Development: Biodiesel is produced using local feedstock. It includes edible oils like soybean, peanut, coconut, palm, etc., and non-edible oils like rapeseed, jojoba, jatropha, etc. [18]. This will provide opportunities for economic support to peasants and facilitate investments in the bioenergy sector. Optimizing the usage of local feedstock will reduce waste and encourage better patterns for sustainable production [19]. Furthermore, community involvement in the biodiesel production process can create jobs to foster standard of living.

iii. Preserving Forests: Producing biodiesel from the renewable resources will save forests and environment. As biodiesel is produced from the local feedstock, it eliminates the need for converting forests or large lands for feedstock farming. This helps preserve forests and natural habitats [20].

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iv. Reduces Oil Dependency: Production of the biodiesel at local levels decreases the dependency on other countries to fulfill the fuel requirements and therefore reduces the imports of fossil fuels. It helps to create energy balance and security.

v. Health Benefits: Many people die every year due to the harmful chemicals released in to the air by the fossil fuels. These emissions cause cancer, lung disease and many other critical diseases. The reduced emissions of the biodiesel reduce pollution, improves air quality and reduces the risks of diseases caused due to pollutions.

vi. Energy Efficiency: Biodiesel is more energy efficient as compared to the petroleum fuels. Biodiesel contains 11% oxygen while Petro diesel does not contain oxygen. Though oxygen does not affect the energy content, it helps in better combustion and low tailpipe emissions. A study by the United States Department of Agriculture (USDA), indicates that for every one unit of fossil fuel used for production, soybean biodiesel produces four and half units of energy as compared to Petro diesel which produces only one unit in return [21].

vii. Vehicle Compatibility: Biodiesel and its blends can be used in diesel engines made after 1991. Cold temperatures may affect the working of biodiesel and clog filters, pipes, and tanks. This issue can be solved by replacing the filter after the first usage and changing it periodically. Vehicles made before 1991 should be monitored to replace the pipes and seals, with Viton-based parts [21].

viii. Safe Product: Biodiesel has a flashpoint temperature of 300°F while diesel fuels have 140°F. This makes biodiesel safer to store and handle than diesel fuels due to less risk of fire hazards. The storage and handling requirements of biodiesel and petrol diesel are nearly similar. Biodiesel being an excellent solvent can dissolve the accumulated deposits in the diesel engine. However, the storage time for biodiesel in these tanks should not exceed six months [22].

Sustainability is at the core of sustainable development goals. It involves all humans on this earth and has three dimensions: environment, economic, and social. The economic benefits of using biodiesel are it helps improve the gross income, becomes a source of revenue for the country due to exports, can be produced locally and does not require importing equipment or machinery, and boosts a nation's self-esteem by demonstrating its capabilities at the global level. The environmental benefits include reducing carbon emissions, reducing toxicity, reducing waste generation, and stabilizing the carbon cycle. It helps to reduce the risks of cancer, neonatal defects, and other respiratory diseases. It is safe to handle and supports other industries that can use biodiesel in some of its processes. The social dimensions of sustainability that can be achieved through biodiesel are it promotes rural development by increasing rural employment. It therefore improves the standard of living of the rural people. It provides energy security and strengthens the economic ability. The availability of fuel supports the growth of new industries in the region, upgrades the existing ones, and promotes sustainable practices in many aspects and sectors.

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Integrated actions and analyzing them for all sectors to decide on modifying industrial processes is a primary step toward achieving SDGs. Biodiesel is a renewable fuel that reduces GHG and carbon emissions. This characteristic helps in achieving SDG 7 (Clean and Affordable Energy). Moreover, reduced emissions ensure healthier surroundings for everyone and reduce the risks of diseases caused by pollution. It is biodegradable and non-toxic. This helps to achieve SDG 3 (Good Health and Well-Being). Furthermore, these reduced emissions and non-toxic particulates protect the health of animals and plants, thus contributing to protecting the life of the land and achieving SDG 15(Life of Land). Biodiesel plants support energy security and improve employment opportunities, especially in rural areas. Additionally, replacing biodiesel with Petro-diesel requires modification. This calls for research and innovation in the industrial sector. The next two SDGs that biodiesel supports are SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry, Innovation and Infrastructure). Moreover, employment opportunities for the people will help overcome poverty and thus contribute towards SDG 1(Zero Poverty). Generating opportunities for rural people and raising their standard of living would decrease the gap between the rural and urban to contribute towards SDG 10 (reduced inequalities). GHG emissions from ships lead to ocean acidification and affect marine organisms. Biodiesel can be used as an alternative to traditional marine diesel. It can be combined with petroleum diesel to be used for ships. Reduction in emissions in seawater will protect marine animals and thus biodiesel would help achieve SDG 14 (life below water).

5. Conclusion

Biodiesel is becoming the most sought fuel for those seeking to protect the environment from pollution and emissions caused by fossil fuels. Its property of being safe for the environment has increased its adaptability and its demand is continuously growing. Moreover, not just climate change, it directly or indirectly contributes to achieving most of the SDGs. It helps to achieve sustainability by supporting economic development, reducing dependency on fossil fuels, and providing health benefits. However, higher production costs, compatibility issues, and availability of feedstock may hinder the adaptability of biodiesel. These challenges can be overcome by encouraging more research and increasing awareness among the people. Renewal of policies and international collaborations would help to bridge the gap in achieving energy requirements for developed and developing economies.

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