**International Journal of Science Academic Research**
Vol. 04, Issue 05, pp.5651-5659, May, 2023
Available online at http://www.scienceijsar.com

ISSN: 2582-6425

**Research Article**

# ROLE OF BIOFUELS IN THE RENEWABLE ENERGY SECTOR

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**Received** 19th March 2023; **Accepted** 25th April 2023; **Published online** 26th May 2023

**Abstract**

Biofuels are energy carriers made from biomass; they can be used for heating and cooling, power generation, and transportation. Biofuels can also be solid, liquid, or gaseous. Nowadays, they seemed to be a significant strategic alternative for diversifying the global energy matrix. However, there is still a lot of ambiguity surrounding the use of biofuels as a sustainable energy source, given that the scientific community is still unsure of the potential long-term environmental implications that biofuels may have. Sources used for the study include academic articles, papers, reports, and statistics from many nations. This paper aims to provide an overview of the many forms of biofuels, highlighting their contribution to sustainability as well as their primary benefits, drawbacks, and uncertainties. Among the main findings are: the demand for biofuels is still highly dependent on the different types of policies implemented by the governments that help encourage the use of biofuels, and the participation of biofuels in the renewable fuels market shows a moderately increasing trend in the period 2011-2021.

**Keywords:** Renewable energy sources, biogas, Sustainable development, markets.

## INTRODUCTION

There is a constant search for new energy sources due to the continuous increase in global energy demand as well as the increase in the temperature of the planet attributed to the burning of fossil fuels, deforestation and different industrial processes. In recent years, much attention has been paid to biofuels, obtained from biomass that can be used as renewable energy in transport, electricity and heating. The growing concern for the care of the environment as well as the depletion of fuels derived from petroleum, has motivated the search for other fuel sources such as biodiesel; however, a complete replacement is impossible due to the production capacity of the companies as well as the compatibility of the motors with these new energy sources [1]. To describe the changes in bioenergy development in the European Union (EU), [2]used different statistical methods and found that most biofuels and renewable wastes are observed in Latvia (31.2 %), Finland (26.7%) and Sweden (24.8%), the highest percentage of wind energy for the year 2015 was in Denmark (7.2%), Portugal (4.3%), Ireland (4, 0%) and Spain (3.5%) and the highest proportion of solar energy in 2015 was found in Cyprus (3.5%), Spain (2.6%) and Greece (2.2%). Regarding geothermal energy, the highest contribution was found in 2015 in Italy (3.5%), Portugal (0.8%) and Slovenia (0.7%); regarding hydroelectric power, Sweden (14.2%), Austria (9.6%) and Slovenia (5.0%) present the highest values. Between the years 2004-2017, the highest coefficients of variation of the share of electricity from renewable energy sources were found in Malta (140.3%), Cyprus (101.1%) and the United Kingdom (71.9%). Regarding the highest coefficients of variation of the proportion of renewable energy sources in heating and cooling in the years 2004-2017, the authors pointed out that these occur in Malta (72.4%), the United Kingdom (69.81 %) and Hungary (44.91%) and in relation to transport in those years, the highest coefficients of variation were found in Finland (113.78%), Malta (115.52%) and Belgium (96.53%). Biofuels are biomass-derived energy carriers used to provide renewable energy services in the form of heating and cooling, electricity, and transportation and include liquid, solid, and gaseous fuels (Lee *et al.,* 2019). Bioenergy such as fast pyrolysis is the only thermal process that directly provides high performance and can be used on-site or transported to centralized facilities for utilization, providing more renewable energy requirements than any other technology, offering greater economies scale and exploitation of biorefineries [3]. An investigation carried out by [4], to analyze the current situation of biofuels as an energy source, using the main specialized sources that publish information in the area and using the techniques of bibliographic review, content analysis and bibliometric analysis to process, analyze and obtain the main trends in publications and patent applications published worldwide in the period 2001-2021, it was found that the technologies to produce biofuels focus on optimizing the technologies in the use and processing of waste and residues. Scientific publications and technological developments in the area of biofuels show a growing trend and the countries with the largest number of publications and patent applications in the area are China and the United States, and the growing trend of publications and patent applications worldwide reflect the importance of biofuels in the energy matrix of renewable fuels around the world. In the biofuels and renewable chemicals sectors, Kircher [5], pointed out that the great demand for raw materials calls for expanding the spectrum of carbon sources, on the other hand, it is necessary to establish circular processing chains and, finally, prioritize product sectors that are as dependent on carbon as are chemicals and heavy fuels. Author points out those high-volume production lines will significantly reduce greenhouse gas (GHG) emissions, but also low-volume chemicals are indispensable in building "low-carbon" industries. Increased investment in sustainable biofuels and chemicals is needed to compete with fossil fuels and chemicals, and many countries adopt comprehensive bioeconomy strategies to meet this

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challenge. He points out to the author that these public actions are mostly biased towards biofuels, but attention should also be paid to renewable chemicals. It is difficult to identify renewable energy alternatives in transportation because the end-user spectrum can range from a single person car to a cargo ship [6]. The authors pointed out that electricity should be prioritized so that in the future it is the fuel used in transport, since it is the most efficient and economical way. However, another form of energy is also necessary, since electricity is not suitable for all means of transport. The results of their research suggest that this fuel will be produced by hydrogenating biomass or carbon dioxide, depending on the residual biomass available. Biomass gasification, steam electrolysis, and carbon capture are key technologies in the future of these fuels, and the author believes that by 2050, some of the proposed renewable fuels would be cheaper than oil. However, they said, this is based solely on fuel production costs and does not consider other costs such as infrastructure. Research examining the impact of increasing the stringency of Renewable Portfolio Standards (RPS) on the consumption of energy produced from renewable sources was carried out by [7]. In it, the researchers focused on technological innovation as well as the economic energy dependence of US states to track how RPS have proliferated and strengthened. They then analyzed the net effect of this RPS evolution on state divestment in fossil fuel energy, to assess the interplay between: a) the political desire to reduce fossil fuel use, b) the technological feasibility of doing so, and c) the economic advantages and disadvantages and the risks. The results of this research indicated that energy security is a priority and even in light of the increased stringency of RPS, states with relatively weak but mandatory RPS are leaders in aggregate renewable energy consumption. This fact is due to the fact that it favors the generation of biofuels and hydroelectric energy, instead of solar and wind energy due to their lower implementation costs. From the previous readings, it can be said that biofuels are a potential source of renewable energy in the transport industry, since they can be used in current infrastructures and require less technological advances than other renewable energy alternatives, such as in electric vehicles and nuclear power. Even though in the literature it is suggested that biofuels could have a negative impact on production and food security, this would depend on the type of feedstock used in the production of biofuels. Advanced biofuels, derived from inedible biomass, are more preferred, however, they require more research and development to reach their full commercialization potential[8]. The authors say that replacing fossil fuels with biofuels can substantially reduce emissions of particulate matter (PM), carbon monoxide (CO), but at the same time increase emissions of nitrogen oxides (NOx), acetaldehyde ($CH_3CHO$), and carbon nitrate peroxyacetyl (PAN), sparking debates about how biofuels should be implemented. However, further studies will be needed to assess the practicalities and associated cost of using biofuel in existing vehicles, particularly to identify any modifications to existing engine infrastructure, the impact of biofuel emissions and their chemistry on climate and human health, to fully determine its suitability as a potential source of renewable energy.

## METHODOLOGY

This work aims to analyze the role of biofuels in the field of renewable energies. In this work, biofuels and their importance as a source of sustainable energy were analyzed. The bibliographic review technique was used to recover the information and the content analysis technique to analyze and interpret the relevant information. To obtain publication trends, the "Analysis" tool of the Lens database was used and it was limited to the period 2011-2021. Only research articles were taken into account and the search was limited to the field title, abstract, keywords and field of study. Specialized information sources in the area were also used, such as: International Energy Agency, International, International Renewable Energy Agency and the Food Agriculture Organization.

### Types of biofuels and their characteristics

Liquid biofuels are considered the preferred route to easily replace current petroleum liquid fuels for transportation, as they involve low investment in infrastructure and offer an immediate route to decarbonize the transportation system. There are various sources of biomass that can be converted into biofuels through thermochemical, physicochemical and biochemical processes [9]. However, there are increasingly attractive alternatives to current liquid fuels and internal combustion engines used in the prevailing transportation system, such as the use of electric vehicles, hydrogen, and compressed biomethane. The authors point out that the benefits of biofuels depend on the feedstock, the conversion pathway and the local context, and efficient conversion pathways, together with biomass from waste or high-yield energy crops, will reduce both the costs of biofuel production and environmental impacts. Compared to petroleum-derived fuels, current commercial biofuels (ethanol, biogas, and biodiesel) typically offer 30-50% carbon emission reductions, but are slightly more expensive. Therefore, the extent of market penetration of biofuels will be influenced by the mix of biofuels and the subsidies. Advanced biofuels promise greater efficiencies and carbon emissions reductions at reduced cost, but more research and development will be required to reach commercialization, which can reduce carbon emissions and improve energy security, as well as enable sustainable agriculture and a better management of natural resources.

The three main types of biofuels are biodiesel, ethanol and biogas ('first generation' biofuels) [10]. Biodiesel is a substitute for diesel and is produced by transesterification of vegetable oils, residual oils and fats; with minor modifications to the engine, biodiesel can serve as a complete replacement for diesel. Kralova & Sjöblom [11] noted that it is biodegradable and non-toxic, significantly reducing toxic and other emissions when burned as fuel. They also said that the advantages of biodiesel as a diesel fuel are its portability, immediate availability, renewability, higher combustion efficiency, non-toxicity, higher flash point and lower sulfur and aromatics content, higher cetane number and higher biodegradability. The authors argued that the main disadvantages of biodiesel are its higher viscosity, lower energy content, higher cloud point and pour point, higher nitrogen oxide (NOx) emissions, lower engine speed and power, injector coking, compatibility engine, high price and higher engine performance. On the other hand, technical disadvantages of biodiesel/fossil diesel blends include problems with fuel freezing in cold weather, reduced energy density, and degradation of fuel stored over long periods of time. The demands for fossil fuels are gradually increasing due to improvements in technology and improvements in the quality of life of the population, which is reflected in the increase in fuel consumption, causing future fuel energy reserves to decrease fossils [12].That is why the increase in energy demand associated with the increase in the

population and its quality of life cannot be met using only fossil fuels. On the other hand, the author points out that those who use first generation crops such as soybeans and corn as bioenergy generate a conflict in relation to the use of food to create energy. Similarly, second generation crops, particularly grasses, are not suitable for biodiesel production. He also mentions that one of the great problems of using second generation vegetable oil is that the life of the engine is shortened if the oil is not refined correctly, in addition to problems related to economic, social and food insecurity, which can be solved with third and fourth generation oils. Biofuels, generated from various types of algae, are highly efficient, have great potential, and compete with food or land. Due to this, the author points out that fourth generation biofuels hold promise to meet the growing energy demands worldwide. However, even though algae culture is simple, its use is complicated due to its high lipid content. Many variables need to be resolved for an algae biofuel to be a commercially viable option to fossil fuels, as the production of biofuels from microalgae is an energy-intensive process. Therefore, the author suggests that these fuels could be potential options to replace fossil fuels, and also recommends considering the potential benefits of using other resources such as future energy sources that are more cost-effective, climate resilient, and sustainable.

Bioethanol is a substitute for gasoline and can be used as a complete substitute in so-called flexible fuel vehicles, it is derived from sugar or starch by fermentation and is a very promising sustainable and ecological energy source [13]. Bioethanol can also serve as a feedstock for tertiary butyl ethyl ether, which mixes more easily with gasoline. Finally, biogas (biomethane) [14] is a fuel that can be used in gasoline vehicles with minor adaptations. It can be produced through the anaerobic digestion of liquid manure and other digestible raw materials.

Biodiesel, bioethanol and biogas are produced from substances that are also used for food. More recently, 'second-generation' biofuels have been produced in a more systematic way. These fuels are produced from biomass in a more sustainable way, which is truly carbon-neutral or even carbon-negative in terms of its impact on carbon dioxide ($CO_2$) emissions. At present, the production of such fuels is not cost-effective because there are several technical barriers that need to be overcome before their potential can be realized. Plant biomass represents one of the most abundant and underutilized biological resources on the planet, and is seen as a promising source of material for fuels and raw materials. As it is most basic, plant biomass can simply be burned to produce heat and electricity. However, there is great potential in the use of plant biomass to produce liquid biofuels.

Rosendo and Soledad [15] points out that different technologies are being researched and developed in order to obtain biofuels. The first generation, such as ethanol, biodiesel and biogas, are obtained from food and forage crops, food waste and wastewater. Second-generation biofuels are obtained from lignocellulosic biomass, including food crops and non-food crops residues, thus producing biodiesel, ethanol, biogas and hydrogen. Third generation biofuels are obtained from biomass of algae or microalgae to generate ethanol, bioethanol, biodiesel, biogas and hydrogen. The fourth generation is obtained from algae and other genetically modified microorganisms, and among these biofuels are biodiesel, bio methane, ethanol, among others [16].

**Role of biofuels in sustainability**

In recent decades, new forms of governance have emerged with various actors not belonging to the nation-state, in order to promote norms and behaviors related to the production and consumption of goods and services with potentially large environmental and social impacts [17]. Organizations have recently developed a series of standards, meta-standards and codes of conduct that attempt to define the conditions under which crops can be grown, as well as their processing and use as fuel. There are few state-sponsored regulations on these crop uses in both the United States and the European Union, for example, by introducing penalties for production associated with direct and indirect land use changecredits for co-production of livestock feed, and promotion of biofuel production on marginal lands. However, these issues are riddled with contradictions, raising questions about how sustainability is defined and assessed in the context of biofuels governance.

Stec & Grzebyk [18] point out that renewable energy sources (RES) are currently the main alternative to fossil fuels and are also seen as an important contributor to curbing dangerous climate change on our planet. Energy supplied from renewable sources can reduce the consumption of primary raw materials and reduce the emissions of harmful substances that enter the atmosphere in the process of electricity and heat production, which has a negative impact on the environment. The authors carried out a multivariate comparative analysis of EU countries in terms of the use of renewable energy. The results of the study confirmed that there was a positive change in the use of renewable energy in most EU countries between 2011 and 2020. The Scandinavian countries, Sweden, Finland and Denmark showed high levels of renewable energy use. By contrast, the lowest use of renewable energy was observed in Poland, Hungary and Slovakia.

Jeswani et al [19] note that biofuels are being promoted as a low-carbon alternative to fossil fuels that could help reduce transportation-related greenhouse gas (GHG) emissions and their impact. in climate change. However, there are also concerns that they may have unintended environmental consequences. The authors said that numerous studies involving life cycle assessment (LCA) have considered climate change and other environmental impacts of biofuels. However, the findings are often contradictory, with a wide variation in the estimates. They said the purpose of their research was to review and analyze the latest available evidence to provide greater clarity and understanding of the environmental impacts of different liquid biofuels and found it evident from their review that the results of the studies LCA tests are highly situational and depend on many factors, including raw material type, production routes, data variances, and methodological choices. Despite this, existing evidence suggests that, in the absence of land-use change (LUC), first-generation biofuels can, on average, have lower GHG emissions than conventional fuels. Fossil fuels, but the reductions for most raw materials 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, as long as there is no LUC. Third generation biofuels do not represent a feasible option at the current stage of development as their GHG emissions are higher than those of fossil fuels. As also discussed by the authors, several studies show that reductions in GHG emissions from biofuels are

achieved at the expense of other impacts, such as acidification, eutrophication, water footprint, and biodiversity loss. Pitonesi et al [20]say that given the growing difficulties in ensuring the supply of oil and derivatives, and the sharp rise in their prices, the adoption of biofuel programs by developed countries, particularly the United States and the European Union, poses a series of opportunities, challenges and risks for the countries of the region. That is why the development of biofuel production must be considered within the framework of national policies so that it can be expressed in a simultaneous advance in economic growth, protection of the natural heritage and social equity. Public policies on biofuels must not neglect the national objectives that have to do not only with productive specialization -Agribusiness- but also with greater energy coverage of the population and the protection of natural heritage. In cases where biofuel production is based mainly on monocultures, it is also necessary to evaluate the impacts on the social conditions that define the labor market, the concentration of ownership and the social distribution of the exploitation benefits. If only monocultures predominate, the contribution of biofuels programs to employment, improvement of distributional asymmetries and rural development could be negative.

**Main advantages, challenges and uncertainties**

The sustainability of bioenergy, and particularly biofuels, is a crucial component of future energy development. Its growth and application have been steadily increasing, possibly due to issues with hydrocarbons and other traditional energy sources. It is important to point out that, as mentioned in previous sections; biofuels can be divided into generations based on the supplies or raw material and the technique used for its production. However, the use of biofuels, like any other product or innovation, has advantages and disadvantages from a socioeconomic, technical and environmental point of view. According to Mogorrón, et al. [21] the future development of biofuels will involve seeking solutions and alternatives to their disadvantages while capitalizing on their advantages. Technically speaking, biofuels are identical to oil in their physical and chemical qualities, making their integration into the automotive sector easier and requiring fewer modifications than other options like hydrogen, electricity, or natural gas [22]. In fact, Coelho, et al. [23]. point out that biofuels are made from agricultural feedstocks, which frequently compete internationally with subsidized goods. They are also conveniently transportable, storable and environmentally superior forms of energy.

Nowadays, many countries consider that it is important to reduce their overdependence on conventional energy sources, particularly oil-importing developing countries that frequently spend a large proportion of their foreign currency reserves on oil imports. Supply security is a very significant potential benefit of using biofuels. In this respect, biofuels stand out as an important strategic option for diversifying the world's energy matrix (for both, developed and developing countries), and they can be produced in a wide range of countries [24]. André [22]agrees that the substantial reliance of industrialized economies on oil is often seen as a threat, since a major amount of this fuel is produced in regions of questionable geopolitical stability. The transition to biofuels makes it possible to reduce, or at least considerably diversify, dependence on external sources, since biofuel production is more feasible for a larger number of nations.

Furthermore, the author maintains that the fact that biofuels are renewable, unlike other traditional fuels such as oil, coal or natural gas, is an undeniable advantage, as it allows current needs to be met while preserving the same natural assets for future generations. Besides, because they are produced mostly from traditional crops, biofuels are simple and familiar to consumers, producers, and those in charge of energy policy. It is believed that Henry Ford and Rudolph Diesel, who are regarded as the fathers of the assembly system and the diesel engine, respectively, foresaw a future in which transportation would be based on fuels derived from plants as ethanol, which has been used as a gasoline additive in many nations for the past 20 years [23].

In addition to the benefits of biofuel production, there would be another significant socioeconomic impact on employment opportunities, mainly in the agricultural sector in rural areas [23], where the widespread use of biofuels will most likely result in higher incomes for farmers as a result of increased demand for agricultural products and, in turn, will provide an additional outlet for products, particularly in countries with surplus agricultural production[25].

André [22] also claims that biofuels, as an energy source, can be an ideal source of job creation, particularly attractive in a context of strong destruction of employment, as the jobs are more intensive than for other energy sources. The author states that this would result in:

- Many nations will enact protectionist measures in response to this activity.
- Given that farmers' incomes have recently been a source of concern, and not infrequently, a source of social conflict, this could decrease the probability of occurrence and recurrence of these events.
- The aforementioned increase in income would most likely contribute to the preservation of rural population centers, which on numerous occasions have been condemned to disappear.

Likewise, the increased use of renewables (primarily biofuels) in rural areas is also closely linked to poverty reduction: According to Coelho et al.[23]more than two billion people worldwide lack access to affordable energy services, putting at risk their chances of benefiting from economic development and improved living standards.

In accordance with those authors the use of biofuels as an alternative energy source along with a greater access to energy services could:

- Increase access to clean, piped drinking water, and cooked food to combat hunger (95% of food requires cooking);
- Lessen the amount of time women and children spend performing essential survival tasks like obtaining water, cooking, and gathering firewood;
- Allow lighting, which boosts security and permits the use of instructional media; chatting at school and doing homework at home at night, for example;
- Lessen deforestation, and the indoor air pollution caused by firewood use, etc.

The benefits of first generation biofuels include ease of processing, low greenhouse gas emissions (with the exception of corn, where the balance of these emissions is almost zero),

and a positive balance in these emissions, according to Maciel [26]. These biofuels are produced using conventional technology such as fermentation (for sugars and carbohydrates), transesterification (for oils and fats), and anaerobic digestion (for waste organics); such as ethanol, methanol and n-butanol (from of sugars), biodiesel (from oils), and biogas (mixture of methane, also known as natural gas, and carbon dioxide, obtained from organic waste).

On the other hand, the advantages of producing second-generation biofuels are mostly focused on the absence of food alterations from agriculture to the energy sector, due to the fact that there are fewer land requirements for this fuel, which reduces competition for land with other agricultural fields, and food fraud [27],[15]. These include ethanol, methanol, synthesis gas, biodiesel and dimethylformamide (DMF). They do not produce co-products like animal feeds and these are intended toreplace traditional petroleum-based fuels, so there are no restrictions on blending or the use of the fuels without blending in existing vehicles. However, the fact that second generation biofuels do not significantly reduce greenhouse gas emissions during the processing of inputs, as opposed to first generation biofuels, is one of their key drawbacks [26]. Nevertheless, this opinion is opposed to that of Datta, Hossain & Roy [27] who assert that second-generation biofuels are more environmentally friendly and produce less greenhouse gasses. Maciel [26] adds that, even though the methods for producing third-generation biofuels are still being developed, pilot plants that have been proven to be effective at capturing anhydride carbon dioxide ($CO_2$) for the production of inputs and maintaining a positive balance in greenhouse gas emissions, have been able to produce biodiesel and ethanol. With the exception of green algae, this contrasts with the utilization of food crops for such inputs. Not to mention, a fourth generation of biofuels produced from genetically altered bacteria that use $CO_2$ or some other carbon source to obtain biofuels. This method, despite being in the theoretical stage, relies solely on the genetic information of artificial bacteria and may have significant thermodynamic limitations. Indeed, compared to other biofuels, it has a higher capacity for $CO_2$ collection and a higher production rate because these algae are obtained with elevated yield and along with high lipid content. The large initial expenditure required for algae cultivation is its main disadvantage [27]. Biofuels are hence more appealing from a social, economic, and environmental standpoint. Therefore, although the biofuels market may really provide long-term economic gains when comparing environmental and societal costs, biofuels frequently appear to be uncompetitive.

It's worth emphasizing that there is now much debate surrounding biofuel issues, making it challenging to come to an agreement. Despite all these benefits, industrialized nations continue to place significant obstacles in the way of biofuels international commerce. The development of biofuels is constrained in developed nations by a number of issues indicated by Coelho et al [23], including:

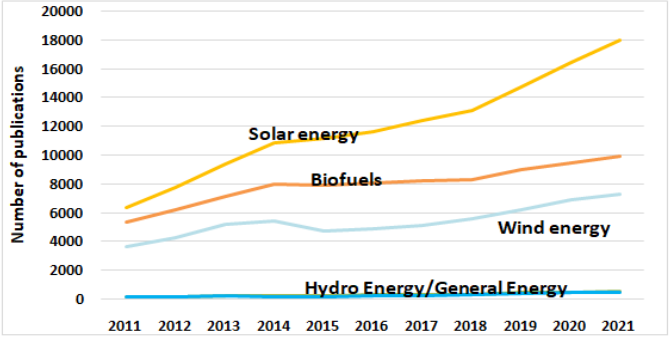
- Their near-exclusive reliance on domestic producers (even in nations that are not naturally suited for the growth of biomass).
- Restrictive regulations (such as blend limits), frequently based on dubious environmental justifications.
- Research and development (R&D) funding that is prioritized toward "clean fossil fuels," which will maintain unsustainable consumption patterns.

Hence André [22]explains that although it has been noted that the increased demand for agricultural products associated with the production of biofuels will benefit farmers, it is also a fact that it can hurt consumers by increasing the cost of staple foods and, ultimately, restricting their access to the most underprivileged.

Furthermore, bioenergy has been marketed as a resource that is sustainable in light of a changing climate. Although it is a renewable energy source, the production of biofuels has a number of environmental drawbacks, such as water and land use changes, which frequently outweigh the potential lower environmental impact compared to fossil fuel alternatives.
For example, in the case of third generation biofuels, the agriculture development costs are higher than other traditional crops, as more energy input is required for algae harvesting and represents roughly around 20-30% of the total manufacturing cost [27]. Likewise, although algae can grow in wastewater, they need a lot of water, nitrogen, and phosphorus to cultivate. Other disadvantage that stands out is related to a current harvesting, storage, and distribution systems that are inadequate for processing and distributing biomass at scale due to high production costs and technical uncertainty, which is inherent to the fact that the commercial scale production of second generation fuels is not yet underway [27]. It has also been noted that biofuels are not very profitable and now rely heavily on government support. Similarly, to the degree that the demand for these items provides producers with a strong incentive, farms may grow and reorient themselves, endangering biodiversity and forest areas, André [22]. To sum up, a complementary set of investments along these lines would need to be made if developing economies are to benefit from the expansion of renewable bioenergy production and also maintain appropriate levels of food security. By making these investments, these nations are expected to benefit consumers of food and energy while also advancing the expansion of their economy and raising the standards of living for everybody, as concluded by Hazell &Pachauri [25].

## Trends of biofuels in the renewable energy market

In order to know how the biofuels market has evolved in the renewable energy sector, a study was carried out on the main trends presented in the publications. In this case, technical scientific articles on biofuels in relation to the main renewable energies, published in the period 2011-2021, were considered. The results show that the international scientific community maintains its interest in carrying out research activities in the area of biofuels as a renewable energy source, as shown in Figure 1.

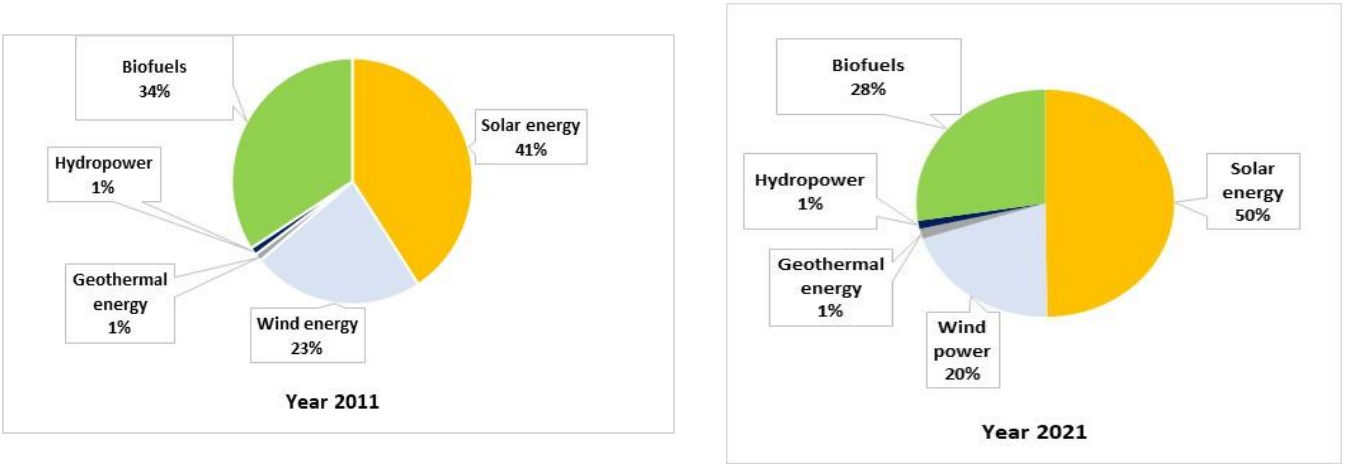



Source:Prepared by authors using data extracted from the Lens.org database [28]

**Figure 1. Trend of publications on renewable energies**

In the figure, it is observed that publications on biofuels present a moderate growing trend, and a greater number of publications compared to wind, hydro and geothermal energy. However, publications related to solar energy show an accelerated growing tendency and a greater number of publications than the ones related to other renewable energies. Likewise, when comparing the distribution of the publications analyzed in 2011 with those of 2021, a 6% decrease in the participation of biofuels with respect to the total number of publications, is observed (see Figure. 2). On the other hand, a more detailed analysis of the publications during the study period reveals that the main areas of publication in the case of biofuels are related to chemical aspects, processes for obtaining biofuels, biodiesel and biogas, as well as environmental sciences.

It is also observed that the Chinese Academy of Sciences is the leader in the area of chemistry; while for the other areas, although it is positioned in the first place, its participation is lower; except in the case of obtaining biodiesel, where the University of Malaysia stands out (see Figure 3). Table 1 presents the main types of renewable energies, as well as the most relevant countries in each of them, their most important institutions, and areas of publication. It can be observed that China and the United States are the countries with publications in all types of energy, and Brazil stands out in the case of hydropower. Another aspect of interest is the new research and development projects to produce biofuels that are being implemented by some of the main oil companies in the world (see Table 2).




Source: Prepared by authors using data extracted from the Lens.org database [28].

**Figure 2. Distribution of renewable energy publications**

**Table 1. Main countries, institutions and areas of publication in renewable energy**

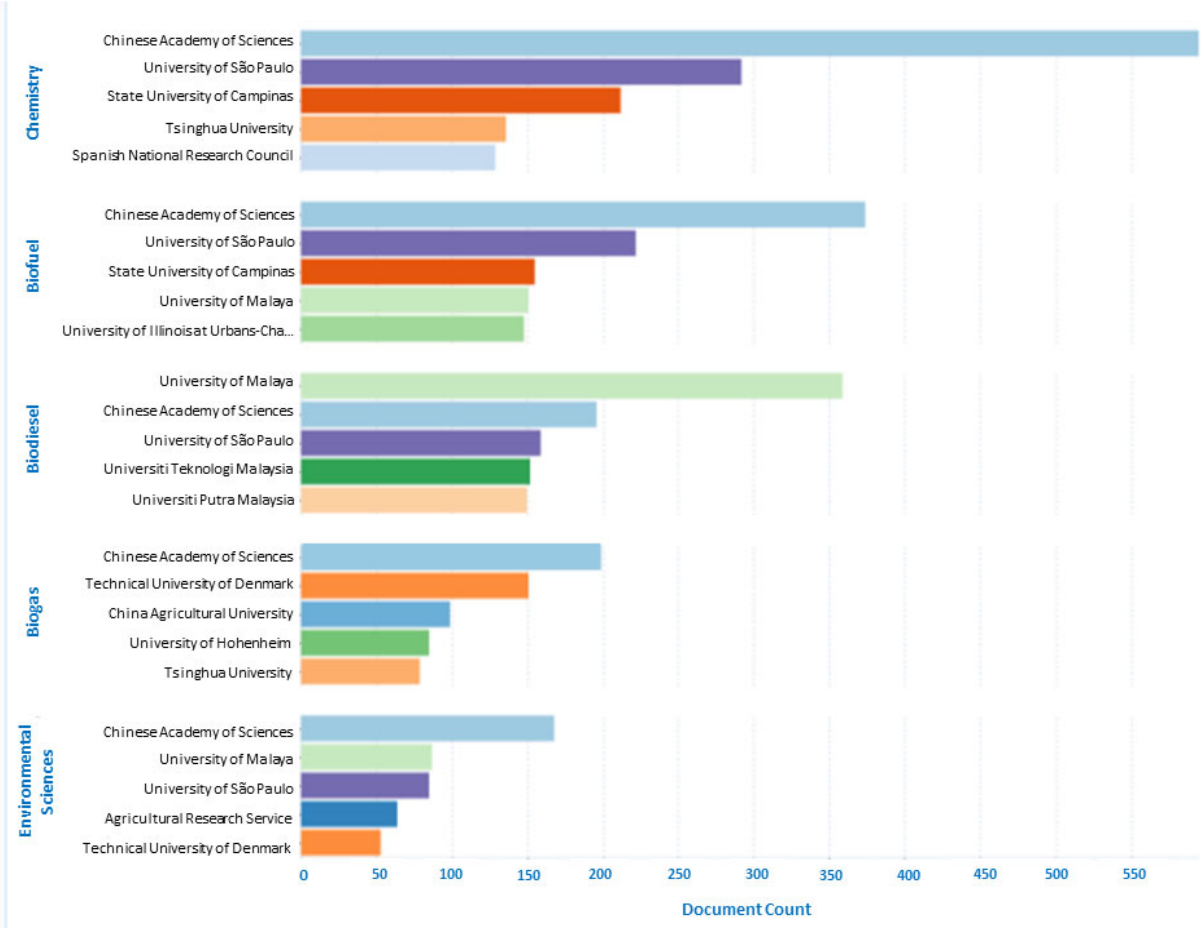
| Type of energy | Countries | Institutions | Areas of publication |
|---|---|---|---|
| Biofuels | China; UnitedStates; India | Chinese Academy of Sciences (China); Spanish National Research Council (CSIC); University of Sao Paulo (Brazil) | Chemistry; environmental sciences; biology; agronomy and biomass |
| Solar energy | China; UnitedStates | Chinese Academy of Sciences (China); National Renewable Energy Laboratory (United States) | Materials science; photovoltaic systems; optoelectronics; computer science. |
| Windenergy | China; United States and United Kingdom | North China Electric Power University (China); Electric Power Research Institute (United States); Technical University of Denmark (Denmark) | Wind energy; engineering and design of turbines/aerogenerators |
| Hydroenergy | Brazil; United States; China and Russia | Russian Academy of Science (Russia); Federal University of Parana (Brazil); Sao Paulo State University (Brazil) | Hydroelectricity; environmentalsciences; engineering |
| Geothermalenergy | China; United States and United Kingdom | Chinese Academy of Sciences (China); China University of Petroleum (China); ETH Zurich (Switzerland) | Geothermal energy; geothermal gradient; environmental science, geology and renewable energies |

Source: Prepared by authors using data extracted from the Lens.org database [28].

**Table 2. Activities of energy companiesin the production of various types of biofuel**

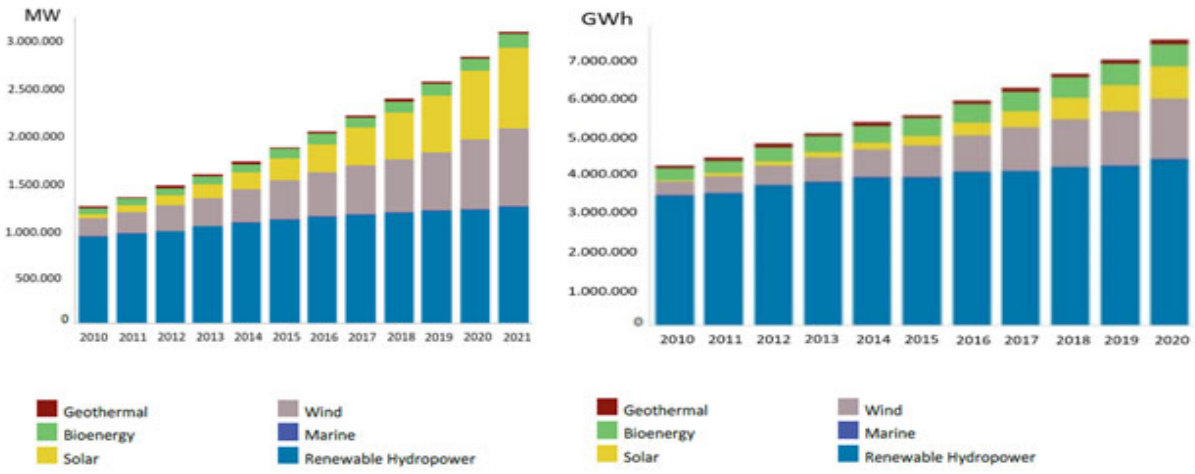
| Country | Company | Activity |
|---|---|---|
| TheUnited of America | Chevron Corporation | - Jointly with American National Laboratory develops technologies for the production of second and third generation biofuels. |
| | Exxon Mobil Corporation | - Researches and develops technology for the production of third generation biofuel from algae (investments amount to more than 600 million dollars); |
| France | Total, S.A. | - Developed and commissioned a high-tech plant for the production of biofuel with algae feedstock<br>- Develops and implements technologies for converting biomass into biofuel based on lignocellulosic biomass, which is the dry matter of plants for the production of bioethanol. |
| The UK | British Petroleum | - Production of biofuels (bioethanol and biobutanol);<br>- Participates in scientific research in the field of new biotechnology in the energy sector in cooperation with the Energy Biosciences Institute, Berkeley National Laboratory and the University of Illinois. |
| TheNetherlands | MarketBiosciencesCorporation | - Biofuelproductionthroughinternationalcooperation |
| Brasil | Petrobras | - Biofuel (ethanol) production accounts for 35% of global consumption;<br>- Exports ethanol (as a vehicle fuel);<br>- invests in the production of biodiesel and the development of biofuel infrastructure, incl. ethanol piping. |

Source: Makhonko, Plotnikova, Tarasova, Varshamova, Yashina [29].




Source: Prepared by authors using data extracted from the Lens.org database [28].

**Figure 3. Main publication areas in biofuels by organization**




Source: IRENA [32].

**Figure 4. Renewable energies: Installed capacity at worldlevel**

**Figure 5. Worldwideelectricitygeneration**

Regarding the global biofuels market situation, biofuels production increased in 2019 in the main producing regions, although at a slower pace than in the previous decade; while their demand has been sustained due to the implementation of different policies. These policies help encourage the use of biofuels, among them: mandatory biodiesel blends with other components, preferential taxes and subsidies, and the growing global demand for the fuel. In some countries, increases in mandates and differential tax systems or subsidies have supported the demand for biofuels and influenced their price [30]. In terms of global biofuel consumption, it is expected to continue to increase, mainly in developing countries, largely driven by the increased use of biofuel blends. In developed countries, the expansion of biofuels will be limited in light of a decline in total fuel demand and reduced policy incentives [30]. According to estimates by the International Energy Agency [31], global demand for biofuels will grow by 41 billion liters, representing 28% in the period 2021-2026. This is mainly due to the implementation of government policies that help encourage their use and also to the increase in demand for fuels in the transportation sector, costs, and the design and implementation of specific policies that promote the use of biofuels. In terms of installed capacity worldwide, biofuels capacity is far below that of other renewable energies.

However, there is a slight upward trend in the period analyzed; which implies an increase of approximately 50% of megawatts during 2011 and 2021. Solar and wind renewable energies are the ones with the largest installed capacity shown, an increasing trend in the same period (see Figure 4). Regarding the use of biofuels to produce electricity, it is observed that until 2016 there was a greater use of biofuels to produce electricity compared to solar energy, which presents an accelerated growing trend; while wind energy has been the most used during the period 2011-2021 (see Figure 5).

**Conclusion**

Since many writers contend that not all of the free consequences of the risky energy sources are favorable, the development and usage of biofuels have not been subject to criticism or debate. The technical advancement of renewable energy sources has both positive and negative implications. The use of biofuels has the potential to provide a number of positive externalities, including a decrease in greenhouse gas emissions, a decrease in air pollution, and the creation of jobs. However, they can put pressure on land usage, drive up food costs, and hurt consumers, particularly the most vulnerable and disadvantaged ones, by emerging as an alternative application for agricultural goods. To the extent that efforts are focused in the right way, avoiding the sector's uncontrolled growth and ensuring that the productive activity is located with economic, social, and environmental sustainability criteria, there is a real chance of creating a genuinely sustainable energy industry based on biofuels. The indirect implications of land use changes must also be managed, local agricultural subsidies must be studied, R&D efforts must be improved, and the potential for biofuel production in each nation must be fully exploited. The participation of biofuels in the renewable fuels market shows a moderately increasing trend in the period 2011-2021, and their installed capacity and production are still well below the rest of the renewable fuels. The demand for biofuels is still highly dependent on the different types of policies implemented by the governments that help to encourage the use of biofuels, such as preferential taxes and subsidies, as well as the mandatory use of biofuel blends with traditional fuels. The increase in demand for biofuels is also due to a higher global demand for energy. Finally, the countries that are most interested in conducting research in the area of biofuels are mainly China and the United States.

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