Chapter

Maize as Energy Crop

Elpiniki Skoufogianni, Alexandra Solomou, Georgios Charvalas and Nicholaos Danalatos

Abstract

Maize is the predominant raw material (together with sugar cane) for the production of bioethanol, the most common and widespread biofuel, and at the same time the predominant raw material for biogas production, with the highest yields in Europe. The advantage of maize biomass over other energy plants is the fact that biomass occurs after harvesting the seed and does not require the use of a different area for its development. The main drawback of the use of maize biomass is the negative effects of removing crop residues on fertility and the physical properties of the soil. Bioethanol's share of global biofuel production is over 94%, as many countries are replacing a portion of their fossil fuels with biofuels, according to international regulations. The choice of crops used as feedstock for the production of bioethanol is strongly associated with local climatic factors. About 60% of world bioethanol production is made with cane raw material in the Central and South American countries, with Brazil leading, while the remaining 40% from other crops with North America producing bioethanol almost exclusively from maize, and the EU uses as raw material raw starch (cereals and maize) as well as crops such as sugar beet and sweet sorghum.

Keywords: maize, bioethanol, biodiesel, bioenergy

1. Introduction

As a result of anthropogenic activities, billions of tons of carbon dioxide deriving mainly from the burning of minerals fuels (oil, coal, and natural gas) as well as other gases, such as methane and nitrous oxide, are annually released into the atmosphere, thus changing the composition of the gases that have remained stable for tens of thousands of years [1, 2]. This overturning is expected to change drastically the climate in the next decades. Its dioxide coal is responsible for 50% of the atmosphere's overheating [3, 4].

Despite the environmental burden, the shifting to alternative forms of energy has begun from the oil crisis in the 1970s and the sudden rise in oil prices. This has led to the first boost for the development of renewable energy sources. In addition to food production, many governments supported the development of new cultivated plants for energy production [5, 6].

However, the fall in oil prices in the 1990s tempered the markets, resulting in hindering green energy development and limiting them to small ones.

Nevertheless in our day and age, global energy requirements have increased sharply due to the rapid increase in both the population and the technology. Therefore, alternative forms of energy are imperative. Research has shown that by

2030, the world's population will have grown from 6 to 8bn (33%) and the demand for energy will increase by 50% [7, 8].

Hopefully, there are many possible alternatives to fossil fuels, especially for heat and power generation. In recent years, we have seen a strong desire for some nations to reduce their confidence in fossil fuels and turn to new forms of energy. Three new markets have emerged for energy crop plants:

- bioenergy;
- biofuels; and
- biorenewable materials [9, 10].

Energy crops are either cultivated or native species, traditional or new, which produce biomass as the main product that can be used for various energy purposes [11]. The biomass produced can be used for combustion or cogeneration for coal, electricity and heating as raw material for thermochemical processes such as pyrolysis and gasification for the production of methanol, biogas and pyrolytic oils and for biochemical processes (for example, fermentation) for the production of ethanol or methane [12, 13].

Their main advantage is that their stable production can ensure a large-scale long-term raw material supply with uniform qualitative characteristics in liquid biofuels and energy plants.

Traditional crops whose final product is used to produce energy and biofuels are also considered as energy crops, such as wheat, barley, maize, sugar beet, sunflower, etc.

"New" energy crops are species with high biomass productivity, per unit of land and divided into two categories which are agricultural and forestry. Agricultural energy crops are further distinguished in annual and multiannual years.

Biofuel compared with fossil fuels is considered to be more effective. For example with coal, oil and natural gas to produce 1 MJ of electricity; non-renewable energy consumption is projected to be between 1.7 and 4.2 MJ; biomass values range from 0.1 to 0.4 MJ. In the case of thermal energy, prices are 1.1 and 1.5 for fossil fuels and only 0.01–0.15 for biomass. Although the energy is considered to be CO_2 neutral, in fact there is actually a burden on greenhouse gas emissions due to the process of cultivation and harvesting. However, this charge does not exceed the total emissions of fossil fuels which results in being up to 90% reduced [14].

The amount of land devoted to the cultivation of energy crops for biomass fuels is estimated to account for only 0.5–1.7% of the available agricultural land. Although there are still strong concerns about the production of plants for energy and not for the classic crops purposes such as fee [15], human food production [16] and other related issues [17], there is no doubt that plant biomass is of paramount importance in this field of renewable energy sources, particularly, in the production of biogas and biofuels, through well-designed and organized development programs [15, 18].

2. Energy crops

Energy crops include plants intended for energy production. One of their main strengths is stable production, which can ensure a large-scale, long-term raw material supply. In particular, new crops have significantly higher yields per unit area than conventional ones. Energy plants produce different types of biomass as main products, which can be used for various energy purposes [19].

For the production of liquid biofuels, the energy crops that can be grown are: sunflower and soybeans. For the production of solid biofuels, plants such as cardoon, eucalyptus, canary grass and switchgrass can be used. Finally, sunflower, maize and others can be used to produce biofuel gas [20, 21].

2.1 Advantage*s* of energy crops

There are many potential benefits using energy crops such as increased economic rural development, energy security and environmental benefits [22]. Rural economic development, a compulsory reason for producing energy from crops is the development of a new and profitable crop market taken into account that in recent years, crop prices have been extremely low, which means low profits.

Energy crops can be planted in degraded cultivated land, pastures and land which is currently used for traditional crops. There are 392 million acres of land potentially eligible for energy crops in the United States.

Using energy crops to produce transport fuels could increase our energy security. Currently, the US is importing over 50% of the oil used for transport fuels and is estimating that imports could increase to 75%. Dependence on foreign imports has significant economic social costs [23].

The environmental benefits of using energy crops include water and soil improvement. By reducing the use of herbicides and pesticides that reduces the chances of water pollution and other environmental problems are also reduced due to non-point pollution. Compared to traditional crops, energy crops have increased soil stability, reduced surface water run-off and reduced nutrient and sediment transport [23].

Reducing the emissions of energy crops against fossil fuels for power generation unlike fossil fuels, plants grown for energy crops absorb the amount of carbon dioxide released during combustion, unlike fossil fuels.

Another advantage of using biomass is the avoidance of atmospheric pollution with sulfur dioxide (SO_2) produced during combustion of fossil fuels which contributes to the phenomenon of "acid rain." The sulfur content of biomass is practically negligible.

Finally, energy crops can ensure employment and the retention of rural populations in the border and other agricultural areas, thus contributing biomass to the regional development of the country [24].

2.1.1 Zea mays L.

Maize (*Zea mays* L.) is a member of the *Poaceae* family. It originates from the American continent where thousands of ancient cultures, such as the Indians, the Magyars and the Aztecs, used to grow it. Today, it is one of the most popular cultivations around the world, such as the United States, China, India and Brazil and produces the largest quantities. Maize is a monocotyledon annual plant wind pollinated, both self and cross pollinated.

Since the sixteenth century, its cultivation has spread to all tropical, semi-tropical and many temperate regions worldwide. It is a crop mainly used for human and animal nutrition [25], but in recent decades, the production of biofuels from maize has redefined the purpose of its cultivation. Today, the contribution of maize to biofuels and especially to bioethanol has increased at levels equal to or higher than all energy plants [26–28]. Nitrogen and ash concentrations as well as lignocellulose are two very important factors that define the quality of the raw material in ethanol. These characteristics, in most cases, are based on climatic conditions as well as on the genome of the plant [29].

2.1.1.1 Maize production

The main root system of maize is rich and can reach a depth of 2.5 m, although its main bulk grows in the first 60 cm of soil.

The pH range for ideal yields is 6–6.5 while a range of 5.8–7 is generally shown, and there are reports that mention an even greater range of 5–8. Generally, attempts have been made to create varieties that adapt to high or low pH in acidic pH, expecting only 35% of ideal yields and being defined as an optimum pH of 6.8 [30].

The water requirements of maize range from 744 to 901 mm. The irrigation frequency affects the yield of corn seed as they propose an irrigation program where a dose of 15% of the water capacity of the soil will be applied irrigation every 9 days [31, 32].

Increased salinity results in reduced plant leaves, decreased green weight, fresh weight, shorter shoots and root lengthening. However, varieties that are ideally adapted to conditions of high salinity have been developed, as they have particular durability [33, 34]. Still hybrids with respect to pure maize rows show greater tolerance to salts [35].

Corn seed germination may be affected even slightly from 28°C or above as the activity of certain protein-producing enzymes is inhibited by this critical temperature and then [36]. When the temperature increases (in the range of 13–38°C), there is a similar increase in leaf growth rate and photosynthesis rate. Also it was found an increase in photosynthesis rate by increasing the temperature (study range, 13–28°C).

The nutrition of the cobbler in continuously cultivated soil suggests 17–23 kg of nitrogen per hectare, while when there is an increase in organic matter, the addition may be twice as low. For high yields, it is necessary to add potassium as a mature crop of maize which may contain up to 30 kg of potassium per hectare in its plant parts. An experiment in Brazil showed that nitrogen application increased the productivity of grains and dry matter, the calorific power, and the potential for energy generation from maize. Maximum grain yield was obtained with an application of 226 kg ha^{-1} N, resulting in 13.647 kg ha^{-1} of grain yield and 10.968 kg ha^{-1} of total biomass. This biomass presents an energy potential of 11.050 kWh ha^{-1}. Taking the use of only husks and cobs into consideration, it is possible to generate 2712 kWh ha^{-1} of bioenergy [37].

Like energy crops, maize is mainly used for two reasons: (i) for the starchy raw material contained in seeds and the material from which bioethanol is mainly produced [38, 39] and (ii) for the biomass (crop residues) resulting from the removal of the seeds and consisting of leaves, stems and a cone of the blade. Biomass can be used for combustion or production of second-generation bioethanol [27, 40, 41].

The appropriate time of harvesting is when the moisture content of the seeds is between 20 and 30% [42]. Late maturation and flowering of maize cause a greater accumulation of lumps with reduced grain yields and a reduced number of cores per plant.

Maize requires more nitrogen and pesticides than many other crops, thus affecting its energy balance. Increasing the energy potential with ethanol from maize is significantly less than with sugar cane [43].

The choice of varieties with a dry matter content of 30–32% is very important for harvesting date to facilitate the process. Based on the system, FAO maize needs about 45 units of heat to form a new real leaf and about 300 units of heat to fully populate the plant. Early varieties (FAO 150–160) require about 2100 heat units, late (FAO 180–210) approximately 2400 units, while biogas crude maize hybrids (FAO 240–260) require a longer period of 2800–3000 heat units.

3. Biofuels

The use of corn-based biofuels was first introduced into the US as a food additive, but ethanol-maize production increased drastically when conventional fuel prices doubled between 2004 and 2007. Biofuels and rising food prices have contributed to the accumulation of wealth in the agricultural sector, thus increasing the income of farmers, potential value to agricultural land and shifting the relative allocation of resources to the agricultural sector in relation to the rest of the economy [44].

The use of biofuels in the transport sector has become very timely recent years.

In **Tables 1** and **2** below, we can see the liquid biofuel production globally and in each continent separately, up to 2017.

3.1 Biodiesel

The European Commission has adopted the Biofuels Directive in 2009, which requires biofuels to contribute 10% of all transport fuels by 2020 [46, 47].

The two main substitutes for conventional fuels are biodiesel and bioethanol. Biodiesel is used in diesel-powered vehicles, while bioethanol is used in gasoline-powered vehicles. The European Union is the major biodiesel producer. USA, Brazil, Argentina, Indonesia and Thailand along with the EU together produce 85% of all biodiesel worldwide. In 2016, 32.6 billion liters of biodiesel were produced globally. Global biodiesel production is expected to reach 39 billion liters by 2024, corresponding to a 27% increase from 2016. It is important to point out that the cost of biodiesel from the first generation biodiesel feedstock is currently 30% higher than of petroleum-based diesel [48]. Furthermore, it is estimated that 60–80% of the biodiesel production cost stems from the cost of raw materials. All this makes use of low-cost second generation biodiesel feedstock which is very attractive alternative [49].

3.1.1 Production

Europe is the world's largest biodiesel producer (**Figure 1**). Total European production in 2016 is estimated at over 1.5 million tons, with Germany and France

	2000	2005	2010	2015	2016	2017
Total	15.9	34.1	94.4	125	132	143
Bioethanol	12.2	24.5	60.5	82.0	85.6	—
biodiesel	0.78	3.42	18.9	28.9	32,6	—
Other biofuels	2.97	6.16	15.0	14.6	13.6	—

Table 1.
Liquid biofuel production globally (all values in billion liters) [45].

	Africa	Americas	Asia	Europe	Oceania
Total	0.07	101	13.9	19.3	0.29
Biogasoline	0.07	72.1	5.95	4.42	0.2
Biodiesel	0.00	12.5	7.48	13.7	0.06
Other Biofu.	0.00	16.0	0.47	1.13	0.00

Table 2.
Liquid biofuel production in continents in 2016 [45].

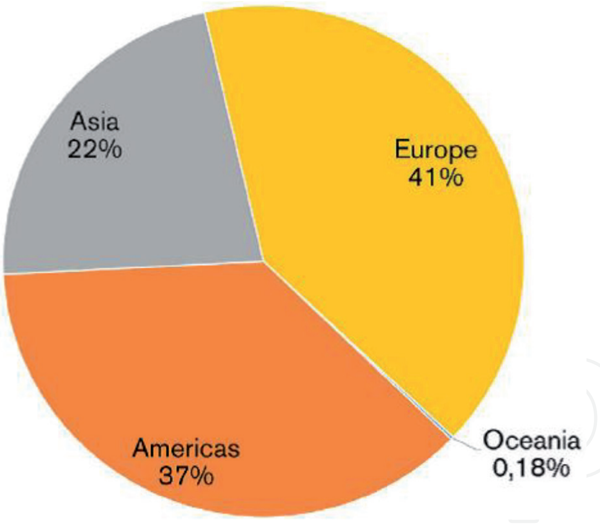

Figure 1.
Liquid biodiesel production in 2016 [45].

being the largest producers within the EU. Italy, the Czech Republic and Austria are also active in biodiesel production [50].

Biodiesel is a generic name for the methyl esters or ethyl esters of organic fatty acids. Biodiesel can be produced from a wide range of seed oils such as oilseed rape, sunflower, soybean and coconut oil.

For example, rapeseed oil is an extremely good substitute for diesel, and it is one of the main oil seeds produced in the European Union. The treatment of plant oil through metallization gives us methyl ester by enabling its ultimate use in diesel vehicles [51].

Seed oils used for biodiesel production come from conventional crops grown by conventional techniques in many parts of Europe. With proper management, crop alternatives may arise as seed oil biodiesel opens a new market for regional economies.

The technology for the production of biodiesel from seed oils has been proven and commercially available for several years. For example, biodiesel is produced from rapeseed by a simple transesterification process, which involves reacting the pulp with small amounts of methanol in the presence of a catalyst. The resultant biodiesel is usually mixed with conventional diesel at the refinery. Biodiesel can also be produced from recycled or used cooking oils, and thus provides a useful outlet for disposal of these oils, which otherwise would have to be disposed of in an environmentally acceptable alternative [52].

3.1.2 Environmental performance

The main advantage of using biodiesel as a transport fuel is that it may have a reduction in greenhouse gas emissions compared to conventional oil use. The use of 100% biodiesel (which is rare) can reduce net CO_2 emissions by 40–50%, respectively, 5% reduces CU2 by 2–2.5% [51].

These calculations are based on a comprehensive life cycle analysis of biodiesel – covering crops, biodiesel production and biodiesel use in the vehicle. In theory, biodiesel can be considered free of carbon, since the carbon emitted during combustion is initially blocked during the growth phase of the cultivated plant. In practice, however, the reduction in emissions from biodiesel from energy crops is lower, because growing and growing plants requires the use of conventional fuels. The use of biodiesel contributes to the creation of an alternative for transport fuels in the context of European Union policy and national climate change policies [51, 53].

Biodiesel can reduce emissions and some other pollutants from vehicles, although this depends on the type of vehicle and the fuel specifications. Biodiesel is a new energy source, aiming to reduce crude oil imports and strengthen security of energy supply in Europe. Biodiesel is easily biodegradable and safe, a property that gives it an advantage for specific uses, such as fuel for boats sailing in ecologically sensitive wetlands.

3.2 Bioethanol

3.2.1 Production

At present, Brazil and the United States (which holds 44% of world production and covered 1.2% of demand for automotive fuel producing 12 billion liters of ethanol) are the largest bioethanol producers of transport fuel worldwide (**Figure 2**), using cane and corn as feedstock, respectively. In Europe, bioethanol is mainly produced from sugar beet and wheat. Spain, Poland and France dominate the bioethanol sector in Europe with a total production of 500,000 tons in 2004. Sweden, Austria and Germany are also active in the production of bioethanol. Production in 2015, after continuing increases, amounted to 58 billion liters. The raw material for bioethanol production is common products from agricultural crops that grow using conventional cultivation techniques in different parts of Europe. Bioethanol production from agricultural crops can be a useful new market for regional economies and help regional development. Bioethanol is prepared by fermenting sugars, starch or cellulose using yeast [54]. The choice of feedstock depends on factors related to cost, technology and economics. Technologies for the production of bioethanol from agricultural products containing sugars and starch are commercially available [55].

Cellulosic materials such as agricultural and forest residues, as well as sorted household waste, are considered as future sources of raw material. However, these materials need to be hydrolyzed before fermentation, using a more complex process than the cereal equivalent. In the long run, cellulosic materials will be considered a potential source of sugars for ethanol production and their use can further reduce CO_2 emissions.

Ethanol production is made from corn grain through two different processes: dry or wet milling. The main difference between the two is the grain processing method. In dry milling, which is the most common procedure, the dried grain is milled into a meal, which is then heated in water to liquefy the starch. Then introduce an enzyme to hydrolyze the starch into sugar, and then is added to ferment the sugar into ethanol and CO_2 [56, 57]. The resulting CO_2 can be used for the production of

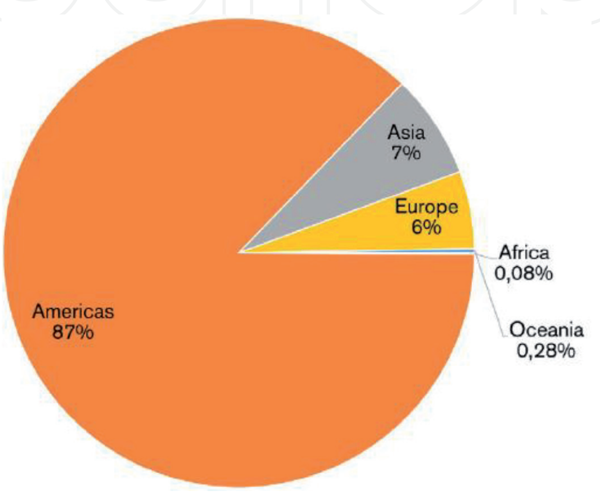

Figure 2.
Liquid bioethanol production in 2016 [45].

carbonated beverages and dry ice and starch-off cereal residues can be marketed for animal feeding (DDGS). During wet milling, the plants, oil (germination) and protein content are separated from the starch (endosperm) in aqueous medium before starch hydrolysis and fermentation begin. With either dry or wet grinding, maize remains a low-cost source of starch that can easily be converted into sugar, fermented and distilled [58].

The choice of crops used as raw material for the production of bioethanol is closely linked to local climatological factors. About 60% of world bioethanol production is produced from sugar cane in the Central and South American countries, with Brazil on the leaf and the remaining 40% from other crops [59], with North America producing bioethanol almost exclusively from maize and the EU uses raw starch (cereals and maize) as well as crops such as sugar beet and sweets. The share of bioethanol in world biofuel production is over 94% with many countries replacing fossil fuels with biofuels [60, 61].

3.2.2 Environmental benefits

The main advantage of bioethanol is that its use results in a significant reduction in greenhouse gas emissions. The use of 100% bioethanol results in a 50–60% reduction compared to conventional fuels. Benefits resulting from the use of blends are obviously smaller [47].

Regarding biodiesel, the benefits of climate change will depend on the raw material to be used to produce bioethanol. GHG (greenhouse gas) emission reductions of 50–60% arise if bioethanol is produced from sugar beet and wheat. If cellulosic materials are used, the net reduction may be greater – perhaps up to 75–80%. This is because less energy is needed for the cultivation of such plants, as well as the fact that during the production phase, energy efficient processes are also used, which also allow the use of renewable energy sources [47].

It is important to understand that bioethanol production is in itself an energy-intensive process and requires significant amounts of energy produced from conventional fuels. However, it is clear that the use of bioethanol can help to achieve the objectives of legislation to prevent climate change. The use of bioethanol can also reduce emissions of other pollutants from vehicles, although this reduction depends on vehicle type and fuel specifications [55, 62].

3.2.3 Disadvantages

There are many concerns about energy crops and bioenergy due to the land and resources needed to produce biofuels. Bioethanol demand in the EU in 2010 amounted to 12.7 billion liters, with domestic production capacity of only 2 billion liters per year [63], so to meet demand it is estimated that it would be about 13% of the total arable land to be used for energy crops [64]. There are serious reactions to the increase in the price of maize and the change of use of limited resources such as cultivated land and water reserves. The use of lignocellulosic corn biomass is an alternative source of biofuels [65].

A major problem in biofuels is the high cost of energy you need to make biomass actively converted [49]. This problem can be solved by research in order to improve the biomass conversion technologies and how it is produced. An important step in the technological field in this direction is the development of second-generation bioethanol production technology from lignocellulosic raw materials, allowing even greater flexibility in the choice of raw materials, releasing much of the arable land from energy production [66].

Finally, a great deal of concern is also given to the biofuels' performance ratio and more specifically to maize from the surveys that have been done to show that the energy efficiency index is positive and can reach 1.5 with more realistic consensus values is 1.25. The net solar conversion efficiency is very low 0.01% (below our initial estimate of 0.045%) [67, 68].

Although second generation bioethanol production technologies from lignocellulosic biomass are still growing, the contribution of maize biomass to bioenergy production is important. The advantage of maize biomass over other energy plants, such as *Miscanthus* x *giganteus*, *switchgrass* (*Panicum virgatum* L.) and others, is the fact that biomass occurs after harvesting the seed and does not require the use of a different area for its development. The main drawback of the use of maize biomass is the negative effects of removing crop residues on fertility and the physical properties of the soil [69, 70].

Corn ethanol is the third most efficient biofuel that yields 1350 l ethanol per hectare. The average US yield in maize is 8.6 mg grains/hectare. Assuming that 25 kilograms of corn grains produce about 10.6 liters of ethanol (a metric equivalent of 1 pounds yields US $ 2.8), the average grain yield translates to 3650 liters/hectare. According to some estimates, the use of ethanol produced from corn cereals offers a 10–20% reduction in GHG emissions compared to petroleum fuels. Maize seed (stem, bark and pellet residues) has the potential to contribute substantially to the biofuel tank when appropriate conversion technologies are developed to convert cellulosic biomass to biofuels. Residues account for about 50% of the cultivation biomass and are readily available in the maize production areas [71].

Several issues need to be resolved before large-scale maize is used to produce biofuels, for example, biodegradation should be at a relatively close distance (about 80 km). From areas where the site will be harvested, transport costs are reduced. The "window" for harvesting the stover will be rather narrow in most places if not removed from the domain.

However, in order for maize to have a sustainable outlook as an energy plant, it is important that the Net Energy Balance (NEB), in the overall production of biofuels from maize growing, be larger than the unit. The term NEB is defined as the fraction between outflows and inputs of the system. The input is considered to be the sum of the fossil fuels required throughout the biofuel production process and includes inputs during the installation and completion of the crop in the field (fertilizers, use of agricultural machinery, agrochemicals, etc.), transportation and the process of converting the seed or biomass into biofuels and as the output of the total energy of the biofuels produced that eventually end up outside the production system. The energy balance in the production of biofuels from maize is reported in the literature in many larger unit studies [72, 73] but also smaller. These differences in the results of the research are identified in the different biofuel production processes but mainly in environmental factors such as climatic and soil conditions, as well as in the cultivation practices followed and influenced the growth and production of maize cultivation [74] since NEB is mainly determined by crop productivity [75].

3.3 Biogas

Biogas production from energy crops is of increasing importance, as it offers significant environmental benefits such as reducing CO_2 emissions. In addition, it can contribute to raising farmers' incomes. Maize has great potential for biogas production. Biogas has the advantage that it can be used in many sectors, such as car fuel, but also as a source of energy in fixed units. Biogas has greater

	2000	2005	2010	2015	2016
Biogas (Billion m^3)	13.2	23.1	38.7	60.0	60.8
Biogas (EJ)	0.28	0.50	0.84	1.30	1.31

Table 3.
Biogas production globally from 2000 to 2016 [45].

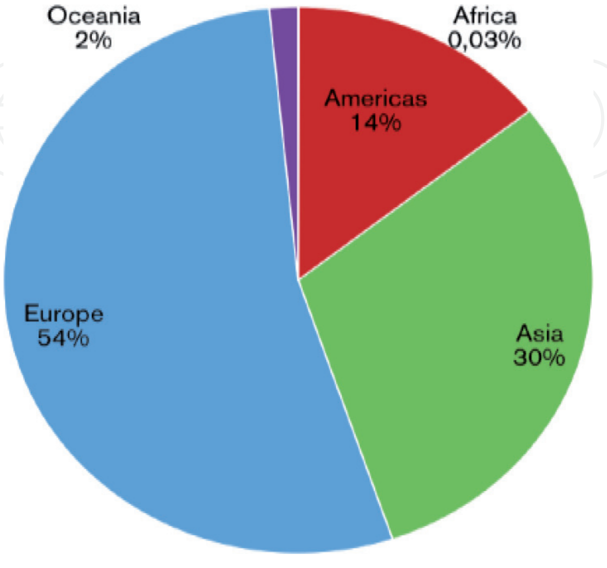

Figure 3.
Biogas production in continents in 2016 [45].

advantages over other biofuels, such as bioethanol for the greater energy that produces, for example, a hectare of corn when converted to bioethanol, giving 20 Gj (Giga Joules). Biogas in the same area gives us nearly three times as much as 55 Gj. Maize, energy beet, rye and grass are crops grown commonly in the central, south-eastern Europe and United Kingdom for energy purposes and mainly for biogas production [74].

Silage maize is digested anaerobically, a conversion process where organic matter of biomass is converted into methane in four phases by bacteria in the absence of oxygen. The end products of the digestion process are biogas and digestate [76, 77].

A major problem we face with maize is its lignocellulos structure which prevents the process of fermenting. Several technologies have begun solving this problem, making maize commercially viable [78, 79]. To help increase the fermentation rate, we cut maize much shorter than a standard loader to increase the surface, which means it will be more accessible to microbes [80].

Recently, lignocellulosic materials have gained more interest as potential candidates for biogas production, but a large-scale implementation has not been widely adopted, mainly because of the complicated structure of the cell walls of lignocellulosic plants, which makes them resistant to hydrolysis by microbial attack. Therefore, the pretreatment of lignocellulosic material is essential step to achieve high process yields [81] (**Table 3**) (**Figure 3**).

4. Conclusions

The rapid development of technology and the constant increase in the number of the world's population combined with the pollution of the environment lead to the need to find new energy resources more friendly and efficient. Energy crops can provide a large amount of energy by exploiting unused agricultural pieces of land or degraded land without burdening environments compared to fossil fuels. Maize is one of the best representatives of energy crops and presents great prospects in the bioethanol sector. Despite the great prospects of energy crops, and in particular maize, we still need research into more efficient use of biomass in cheaper and more economical ways.

Conflict of interest

The authors declare no conflict of interest.

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References

[1] Abdus S, Toshikuni N. Impact of human activities on carbon dioxide (CO_2) emissions: A Statistical Analysis. The Environmentalist. 2005;**25**(1):19-30. doi.org/10.1007/s10669-005-3093-4

[2] Hao X, He J, Zhao H, Zhang Q. Investigation of the absorption coefficient of methane in pollution gas measurement. Optik—International Journal for Light and Electron Optics. 2015;**126**(14):1385-1388. DOI: 10.1016/j.ijleo.2015.04.016

[3] Sabine CL, Feely RA. Climate and climate change. Carbon Dioxide. Encyclopedia of Atmospheric Sciences. Eds John Pyle & Fuging Zhang, Elsevier Ltd. 2015. pp. 10-17. DOI: 10.1016/b978-0-12-382225-3.00095

[4] Florides AG, Christodoulides P. Global warming and carbon Dioxide through sciences. Pubmed. Environmental International. 2008;**35**(2):390-401. DOI: 10.1016/j.envint.2008.07.007

[5] Karp A, Halford N. Energy crops: Introduction. Series. Nigel GH, Angela K, editors. Royal Society of Chemistry. RSC Energy and Environment. 2010;**1**:1-12. DOI: 10.1039/9781849732048-00001

[6] Sims REH, Hastings A, Schlamadinger B, Taylor G, and Smith P. Energy crops: Current status and future prospects. Global Change Biology. 2006;**12**(11):2054-2076. DOI: 10.1111/j.1365-2486.2006.01163.x

[7] Glenn J, Warner K. The 21st century population-energy-climate nexus. Elsevier LTD, Energy policy. 2016;**93**:206-212. DOI: 10.1016/j.enpol.2016.02.044

[8] Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC. OJ, L 140; 2009. pp. 88-113

[9] Röder M, Welfle A. Bioenergy. Managing Global Warming. Eds Trevor Letcher, Elsevier Academic press. 2019. pp. 379-398. DOI: 10.1016/b978-0-12-814104-5.00012

[10] Eichhorn S, Gandini A. Materials from Renewable Resources. MRS Bulletin, Cambridge Core. 2010;**35**(3):187-193. DOI: 10.1557/mrs2010.650

[11] Harvey M, Pilgrim S. The new competition for land: Food, energy, and climate change. Food Policy. 2011;**36**:S40-S51

[12] Ness J, Moghtaderi B. Chapter 1: Biomass and Bioenergy, Coal-Biomass Cofiring Handbook. Cooperative Research Centre for Coal in Sustainable Development. 2007. pp. 1-36. Available from: https://www.researchgate.net/publication/309127353_Chapter_1_Biomass_and_Bioenergy

[13] Voloshin RA, Rodionova MV, Zharmukhamedov SK, Nejat Veziroglu T, Allakhverdiev SI. Review: Biofuel production from plant and algal biomass. International Journal of Hydrogen Energy. 2016;**41**(39):17257-17273. DOI: 10.1016/j.ijhydene.2016.07.084

[14] Ingenito A, Andriani R, Agresta A, Gamma F. A comparative study of combustion between biofuels and fossil fuels. 2012. DOI: 10.2514/6.2012-4054

[15] Cherubini F, Stroemman AH. Production of biofuels and biochemicals from lignocellulosic

biomass: Estimation of maximum theoretical yields and efficiencies using matrix algebra. Energy and Fuels. 2010;**24**(4):2657-2666

[16] Knocke C, Vogt J. Biofuels–challenges & chances: How biofuel development can benefit from advanced process technology. Engineering in Life Sciences. 2009;**9**(2):96-99

[17] Serio MA, Kroo E, Wojtowicz MA. Biomass pyrolysis for distributed energy generation. Preprint Symposium American Chemical Society, Division of Fuel Chemistry. 2003;**48**(2):584-589

[18] Larson ED. A review of life-cycle analysis studies on liquid biofuel systems for the transport sector. Energy for Sustainable Development. 2006;**10**(2):109-126

[19] Jezierska-Thöle A, Rudnicki R, Kluba M. Development of energy crops cultivation for biomass production in Poland. Renewable and Sustainable Energy Reviews. 2016;**62**:534-545. DOI: 10.1016/j.rser.2016.05.024

[20] Claverie M, Demarez V, Duchemin B, Hagolle O, Ducrot D, Marais-Sicre C, et al. Maize and sunflower biomass estimation in Southwest France using high spatial and temporal resolution remote sensing data. Remote Sensing of Environment. 2012;**124**:844-857. DOI: 10.1016/j.rse.2012.04.005

[21] Epplin FM. Cost to produce and deliver switchgrass biomass to an ethanol-conversion facility in the southern plains of the United States. Biomass and Bioenergy. 1996;**11**(6):459-467. DOI: 10.1016/s0961-9534(96)00053-0

[22] Dembris A. Importance of biomass. Energy Sources. 2004;**26**:361-366

[23] Tolbert VR, et al. Soil and water quality aspects of herbaceous and woody energy crop production: Lessons from research-scale comparisons with agricultural crops. In: Conference Proceedings on Bioenergy. Madison; 1998. p. 1272

[24] Western Regional Biomass Energy Program. Environmental Issues. Biomass Digest. 2017;**4**(2):3

[25] Klopfenstein TJ, Erickson GE, Berger LL. Maize is a critically important source of food, feed, energy and forage in the USA. Field Crops Research. 2013;**153**:5-11. DOI: 10.1016/j.fcr.2012.11.006

[26] OECD. Proceedings of Biomass and Agriculture—Sustainability Markets and Policies. Paris: OECD; 2015. ISBN: 92-64-10555-7

[27] Karp A, Shield I. Bio energy from plant and sustainable yield challenge. New Phytologist. 2008;**179**:15-33

[28] Dhugga K. Maize Biomass Yield and Composition for Biofuels. Crop Science. 2006;**47**(6):2211-2227. DOI: 10135.2/cropsci2007.05.0299

[29] Muhaji, Sutjahjo DH. The characteristics of bioethanol fuel made of vegetable raw materials. The Consortium of Asia-Pacific Education Universities (Cape U). IOP Conferences Series: Materials Science and Engineering. 2018;**296**:1-7. DOI: 10.1088/1757-899X/296/1/012019

[30] Greaves JA, Rufener GK II, LeRette RJ, Stoecker MA. High pH tolerant corn and the production thereof. United Stated Patent. 1996

[31] Kara T, Biber C. Irrigation frequencies and corn (*Zea mays* L.) yield relation in northern Turkey. Pakistan Journal of Biological Sciences—PJBS. 2008;**11**(1):123-126

[32] Kranz WL, Irmak S, Van Donk J, CD Yonts, Martin DL. Irrigation Management for Corn. NebGuide.

Lincoln Extension: University of Nebraska; 2008

[33] Faustino FC, Garcia RN, Agtarap ML, Tecson-Mendoza EM, Lips SH. Salt tolerance in corn: Growth responses, ion accumulation, nitrate reductase and PEP-carboxylase activities. Philippine Journal of Crop Science. 2000;**25**(1):17-26

[34] Akram M, Ashraf R Ahmad M, Waraich J Iqbal EA, Mohsin M. Screening for salt tolerance in maize (*Zea mays* L.) hybrids at an early seedling stage. Pakistan Journal of Botany. 2010;**42**(1):141-154

[35] Maiti RK, Kousik SK, González Rodríguez H, Rajkumar D, Vidyasagar P. Salt tolerance of twelve maize hybrids at the seedling stage. Acta Agronomica Hungarica. 2010;**58**:21-29

[36] Riley GJP. Effects of high temperature on the germination of maize (*Zea mays* L.). Planta. 1981;**151**:68-74

[37] Ambrosio R, Pauletti V, Barth G, Povh F. Energy potential of residual maize biomass at different spacings and nitrogen doses. Ciencia e Agrotecnologia. 2017;**41**(6):626-633. DOI: 10.1590/1413-70542017416009017

[38] Morris M, Hill A. Ethanol Opportunities and Questions. Fayetteville, Arkansas: ATTRA–National Sustainable Agriculture Information Service; 2006

[39] Persson T, Garcia A, Paz J, Jones J. Maize ethanol feedstock production and net energy value as affected by climate variability and crop management practices. Gerrit Hoogenboom Agricultural Systems. 2009;**100**:11-21

[40] Sanchez OJ, Cardona CA. Trends in biotechnological production of fuel ethanol from different feedstocks. Bioresource Technology. 2008;**99**(13):5270-5295

[41] Balat M. Production of bioethanol from lignocellulosic materials via the biochemical pathway: A review. Energy Conversion and Management. 2011;**52**(2):858-875

[42] Agronomy corn. Grain Harvesting. University of Wisconsin. 2006. Available from: http://corn.agronomy.wisc.edu

[43] Donato P, Finore I, Poli A, Nicolaus B, Lama L. The production of second generation bioethanol: The biotechnology potential of thermophilic bacteria. Journal of Cleaner Production. DOI: 10.1016/j.jclepro.2019.06.152

[44] Xavier AMRB, Correia MF, Pereira SR, Evtuguin DV. Second-generation bioethanol from eucalypt sulphite spent liquor. Bioresource Technology. 2010;**101**(8):2755-2761

[45] WBA Global Bioenergy Statistics. Summary Report. 2018. Available from: https://worldbioenergy.org/

[46] Rutz D, Janssen R. Biofuel Technology Handbook, WIP Renewable Energies ISBN contract No. EIE/05/022/SI2.420009. Mónchen, Germany; 2008

[47] Pahl G. Biodiesel: Growing a New Energy Economy. Vermont: Chelsea Green Publishing Company; 2005

[48] Rouhany M, Montgomery H. Global Biodiesel Production: The State of the Art and Impact on Climate Change. 2018. doi.- org/10.1007/978-3-030-009854_1

[49] Bušić A, Kundas S, Morzak G, Belskaya H, Marđetko N. Recent Trends in Biodiesel and Biogas Production. Food Technology and Biotechnology. 2018;**56**(2). DOI: 10.17113/ftb.56.02.18.5547

[50] Tyson KS. Biodiesel Technology and Feedstock. NREL. State of Michigan, Senate Ag Preservation Task Force,

Senate Ag Preservation Task Force Report 2003; 1999. p. 1

[51] Biodiesel. 2018. Available from: www.biodiesel.org. [Assessed: 25 June 2019]

[52] Tickell J. From the Fryer to the Fuel Tank: The Complete Guide to Using Vegetable Oil as an Alternative Fuel. Hollywood, CA: Tickell Energy; 2003

[53] Kim SD, Dale BE. Environmental aspects of biofuel derived from no-tilled corn grain: Nonrenewable energy consumption and greenhouse gas emissions. Biomass and Bioenergy. 2005;**28**:475-489

[54] Zabochnicka M, Sławik L. Bioethanol-Production and Utilization, 2010. https://www.researchgate.net/publication/228351087_BioethanolProduction_and_Utilizaton

[55] Dufey A. Biofuels Production, Trade and Sustainable Development: Emerging Issues. Environmental Economics Programme/Sustainable Markets Group; 2006

[56] Prasad RK, Chatterjee S, Mazumder PB, Gupta SK, Sharma S, Vairale MG, Gupta DK. Bioethanol production from waste lignocelluloses: A review on microbial degradation potential. Chemosphere. PMID 31154237. 2019;**231**:588-606. DOI: 10.1016/j.chemosphere.2019.05.142

[57] Sewsynker-Sukai Y, Gueguim Kana EB. Simultaneous saccharification and bioethanol production from corn cobs: Process optimization and kinetic studies. Bioresource Technology. 2018;**262**:32-41. DOI: 10.1016/j.biortech.2018.04.056

[58] Demirbas A. Bioethanol from cellulosic materials: A renewable motor fuel from biomass. Energy Sources. 2005;**27**(4):327-337

[59] Gonzalez-Garcia S, Gasol CM, Gabarrell X, Rieradevall J, Moreira MT Feijoo G. Environmental aspects of ethanol-based fuels from Brassica carinata: A case study of second generation ethanol. Renewable and Sustainable Energy Reviews. 2009;**13**(9):2613-2620

[60] Mussatto SI, Dragone G, Guimaraes PMR, Silva JPA, Carneiro LM, Roberto IC, et al. Technological trends, global market, and challenges of bio-ethanol production. Biotechnology Advances. 2010;**28**(6):1873-1899

[61] David P, Marklein A, Megan A, Karpoff TM, Gillian S, McCormack PR, et al. Biofuel Impacts on World Food Supply: Use of fossil fuel, land and water resources. Energies. 2008;**1**(2):41-78. DOI: 10.3390/en1010041

[62] Zarzyycki A, Polska W. Bioethanol production from sugar beet-European and polish perspective. In: The First TOSSIE Workshop on Technology Improvement Opportunities in the European Sugar Industry; 25-26 January 2007; Ferrara, Italy; 2007

[63] Magar SB, Pelkonen P, Tahvanainen L, Toivonen R, Toppinen A. Growing trade of bioenergy in the EU: Public acceptability, policy harmonization, European standards and certification needs. Biomass and Bioenergy. 2011;**35**(8):3318-3327

[64] Bacovsky D, Mabee W, Worgetter M. How close are second generation biofuels? Biofuels, Bioproducts and Biorefining. 2010;**4**(3):249-252

[65] BP. Statistical Review of World Energy 2010. Bp.com/statistical review

[66] Naylor R, Liska A, Burke M, Falcom WP, Gaskell J, Rozelle S, et al. Ripple effects of crop-based biofuels on global food security and the environment. Environment. 2007;(49):30-43

[67] Perlack RD, Wright LL, Turhollow AF, Graham RL, Stokes BJ, Erbach DC. Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply. Oak Ridge, TN: USDOE; 2005

[68] Wright LL, Boundy B, Perlack B, Davis S, Saulsbury B. Biomass Energy Databook. 1st ed. Oak Ridge, TN: USDOE; 2006

[69] Ragauskas AJ, Williams CK, Davison B, Britovsek G, Cairney J, Eckert CA, et al. The path forward for biofuels and biomaterials. Science. 2006;**311**(5760):484-489

[70] Kumar D, Singh V. Bioethanol Production From Corn. Corn. 2019. pp. 615-631. DOI: 10.1016/b978-0-12-811971-6.00022-x

[71] Tilman D, Hill J, Lehman C. Carbon-negative biofuels from low-input high-diversity grassland biomass. Science. 2006;**314**:1598-1600

[72] Patzek TW, Anti SM, Campos R, Ha KW, Lee J, Li B, et al. Ethanol from corn: Clean renewable fuel for the future, or drain on our resources and pockets? Environment, Development and Sustainability. 2005;7:319-336

[73] Hoogenboom G. Contribution of agrometeorology to the simulation of crop production and its applications. Agricultural and Forest Meteorology. 2000;**103**:137-157

[74] Martinov M, Golub M, Viskovic M, Djatkov D, Krstic J. Study of Harvest, Storage and Processing of Corn Stover for its Use as a Fuel and Feedstock for Biofuels in Autonomous Province Vojvodina. NoviSad, Serbia: Faculty of Technical Sciences; 2016. Available from: http://www.psemr.vojvodina.gov.rs/images/Studije/Biomasa/Kukuruzovina_kao_energent_i_sirovina_za_biogorivo.pdf

[75] Lorenz D, Morris D. How Much Energy Does it Take to Make a Gallon of Ethanol? Washington D.C: Institute for Local Self-Reliance (ILSR); 1995

[76] Verstraete W. Biogas. 1st ed. Stichting Leefmilieu v.z.w., Antwerpen VZW – dossier nr. 6. p. 207

[77] Mol APJ. Bounded Biofuels? Sustainability of Global Biogas Developments. Science, Technology and Sustainability. John Wiley & Sons Ltd; 2013. https://doi.org/10.1111/soru.12026

[78] Lizasoain J, Trulea A, Gittinger J, Kral I, Piringer G, Schedl A, et al. Corn stover for biogas production: Effect of steam explosion pretreatment on the gas yields and on the biodeg-radation kinetics of the primary structural compounds. Bioresource Technology. 2017;**244**:949e956. DOI: 10.1016/j.biortech.2017.08.042

[79] Schroyen M, Vervaeren H, Hulle SWH, Van Raes K. Bioresource technology impact of enzymatic pretreatment on corn stover degradation andbiogas production. Bioresource Technology. 2014;**173**:59e66. DOI: 10.1016/j.biortech.2014.09.030

[80] Oslaj M, Mursec B, Vindis P. Biogas production from maize hybrids. Biomass and Bioenergy. 2010;**34**(11):1538-1545. DOI: 10.1016/j.biombioe.2010.04.016

[81] Maryam M, Forgács G, Horváth I. Biogas from Lignocellulosic Materials. Keikhosro K, editors. Springer, Cham. 2015. doi.org/10.1007/978-3-319-14033-9_6