Developmental Perspectives of the Biofuel-Based Economy

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1 Introduction

1.1 Substituting Fossil Fuels to Reverse Climate Change

Currently, there is a high dependence on fossil resources to produce energy and raw materials. Oil derivatives continue to be the primary source of energy consumption worldwide, representing 31% of the energy consumed, followed by coal with 26% and gas with 23% in 2019. According to current data, there is still many unexploited fossil energies. In the case of oil, specifically, there are 1,700,803.80 million barrels (Eurostat, 2020; International Bank for Reconstruction and Development, 2020; National Center for Information on Hydrocarbons (CNIH), 2020; Víctor, 2013). However, the current consumption rate is untenable in the long term. In recent centuries, a large amount of fossil fuels has been extracted and used, approximately 80%, 50% and 30% of the total existing coal, gas and oil reserves, respectively. Besides this, a climatic emergency is pushing alternative energy sources in transport, heating and industry. These reserves must remain underground to reduce greenhouse emissions; otherwise, the combustion of oil, natural gas and carbon would increase the global

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mean temperature by more than 2 °C (Pellegrini et al., 2021). Carbon dioxide (CO_2), nitrous oxide (NO_2), ozone (O_3) and methane (CH_4) can emit and absorb infrared radiation, ensuring a mild temperature in the atmosphere. Expansion of industry, transport and agriculture based on fossil fuels has increased the levels of these gases in the atmosphere (Hu et al., 2021).

Consequently, there is an unwanted increase in the average temperature. By transforming the energy sector towards a renewable perspective based on the substitution of petroleum derivatives, environmental, social and economic benefits will be achieved. The main renewable sources that allow this transformation are biomass, solar energy, wind energy and biofuels such as bioethanol, biodiesel, biomethane and biobutanol (Bertheau, 2020). In the case of biomass and biofuel, renewable feedstock must be utilized to ensure sustainability, for instance, agricultural and forestry wastes.

1.2 Biofuels and the Circular Economy

The world's population by 2050 will reach 9 billion inhabitants according to the most recent forecast (United Nations, 2021), which means a concomitant increase in the demand for food and feed and a subsequent increase in waste production. The transformation of these wastes into bioenergy has been pointed out as the solution for sustainable development. During the last decade, agricultural waste production accounted for a potential generation of 90 million tonnes of oil equivalent (MTEP), which is considerably higher than any other existing by-product, such as wood chips (57 MTEP) from municipal waste (42 MTEP). The waste generated in agricultural and livestock activities has been on the rise in recent. If agricultural wastes are insufficiently managed, environmental problems arise as a cause of soil and water pollution or indirect greenhouse gas emissions (GHG). In this scenario, waste can be considered a helpful resource to generate energy and high-value products. The conversion of agricultural, livestock and forestry residues into bioenergy is currently used to reduce consumption and dependence on fossil fuels. Increasing the transformation of waste materials into bioenergy is a crucial process for sustainable development during the next decades. Agricultural residues present advantages over other residues (such as urban wastes) due to their inherent features: homogeneous chemical composition, well-known processing techniques and ubiquity production. The use of wastes as an energy source to produce biofuels and the obtaining of high-value chemical compounds can be a great step for the proper development of the circular economy (Song et al., 2020).

1.3 Energy Demand

Concurrently to the population growth, expansion of cities and towns has increased the energy consumption, accounting for around 30% of world energy consumption with an increasing trend. Energy consumption in 2019, by the residential and commercial sector, in the USA was approximately 6.24 million megawatts hour (MWh), which is equivalent to 28% of end-use energy consumption (Dong et al., 2021). Nowadays, most of the buildings present low and medium energy efficiency. Therefore, there is a large scope for improvement (Luo et al., 2021).

The transport sector represents more than a quarter of the total energy consumed worldwide, 26% (Sandoval-García et al., 2021). In the USA, only 5% of energy is used in biofuels. The rest comes from fossil sources, with gasoline being the most used fuel, 56%. The deployment of electric vehicles has grown rapidly in the last decade, with 10 million vehicles in use by the end of 2020. China has the most electric vehicles in stock, 5.4 million, followed by Europe with 3.3 million and the USA, which has 1.8 million. Worldwide, it has gone from having zero electric vehicles to having 11.3 million in stock (International Agency for Energy, 2021).

Regarding GHG emissions, the electric vehicle is not neutral since an important amount of the electricity to recharge the batteries currently could involve utilizing fossil sources. In this scenario, it is necessary to opt for alternative energy sources such as biofuels (Neves et al., 2017).

Countries with emerging economies are at the centre of concern, as they have experienced rapid economic growth and high energy use and are deeply affected by economic globalization. As the world's largest developing and growing economy, China accounted for 24% of global energy consumption and 34% of global energy consumption growth in 2018 (Acheampong et al., 2021).

In 2019, in the EU-27, energy derived from renewable sources accounted for 19.7% of the energy consumed, just 0.3% below the 2020 target of 20%. In the USA, energy production from renewable sources accounted for about 12% of total energy production (Lahiani et al., 2021). Governments have numerous incentives to promote the implementation of energy efficiency since this generates economic, social and environmental benefits (American Council for an Energy-Efficient Economy, 2019) (see Sect. 4).

1.4 Current Situation of Biofuels

To achieve the United Nations (U.N.) Sustainable Development Goals (SDGs), efforts must be focused on increasing electricity production from renewable sources and heat and fuels from residual biomass. This fact is the focus of various global development initiatives. At present, electrical energy comes from the following sources with their respective installed power 142 GW for photovoltaic solar energy, 80 GW for wind energy, 32 GW for hydroelectric energy and 12 GW for other renewable energies, according to data from the International Agency for Energy (IEA, 2021). Electricity production through renewable sources such as solar or wind generates great intermittence and uncertainty when adjusting the supply with the energy demand since they depend greatly on meteorology and seasonality. Therefore, it is necessary to opt for other renewable energy sources that ensure a continuous energy supply, especially in the heavy transport sector and heat supply (Abedinia et al., 2019).

Regarding raw materials to produce biofuels, there is a positive trend towards using agricultural wastes, such as biological and municipal waste and sewage sludge (Zhu et al., 2021), to the detriment of the use of grain generated in energy crops. The traditional sources for producing biofuels come from energy crops (sugarcane, beet and oleaginous seeds). These materials compete with the cultivated areas for food and feed production; in addition, pollution due to chemical fertilizers and large consumption of water endangers sustainability in the long term. By using the residues (such as straw), which are generated from the crops destined for food, to obtain biofuels, the contamination risks are reduced, and GHG emissions of the food production process are reduced. This trend is expected to continue since, in this way, energy generation does not conflict with the food sector (Yu et al., 2022). According to the report prepared by the Renewable Energy Association, the supply and demand for biofuels have increased in the last 20 years, especially the production of bioethanol, which grew by around 1000% between 2000 and 2020.

Regarding the development of systems to produce biomethane, in recent years, Europe has seen a significant increase in the production of this biofuel with an average annual rate of 20% (European Biogas Association, 2020). In recent years, new techniques for biogas improvement such as Cryobox-Bio are being developed in which biogas polishing and liquefaction processes (Bio-LNG) are integrated, which provides a methane recovery rate higher than 99%, and low-cost photosynthetic upgrading techniques with biomethane yields of more than 95%. Both technologies provide clean biomethane suitable for transportation, power generation and the energy industry (Rodero et al., 2019).

Biofuels produced from agricultural residues can provide energy products compatible with the current energy infrastructure (Kurczyński et al., 2021; Millo et al., 2021). Biofuels can be used in transportation, industry and heating in pure form or mixed with fossil derivatives. Therefore, the introduction of biofuels provides a transition for energy sustainability in the transport, industrial and construction sectors. By using biofuels, air pollution and GHG emissions are reduced. These biofuels are considered CO_2-neutral since the carbon embodied comes from atmospheric carbon dioxide previously fixed from biomass.

Furthermore, biofuels have a greater capacity to reduce greenhouse gas emissions during the life cycle than electricity (Andersson & Börjesson, 2021). Therefore, replacing fossil fuels with biofuels makes it possible to reduce global warming (Scovronick & Wilkinson, 2013). However, it is necessary to combine electrical energy from renewable sources with the use of biofuels.

According to data from the International Energy Agency (IEA) 2013, oil consumption will decrease relative to its global market share by at least 5% by 2040.

This reduction will be based on a continuous substitution by renewable electricity and energy products. Liquid biofuels, such as bioethanol and biodiesel, are more frequently used to replace fossil fuels in the transportation sector. These biofuels are essential to mitigate climate change, revitalize agricultural economies and achieve a secure energy supply with low CO_2 emissions (Løkke et al., 2021a). The production and consumption of biofuels have increased worldwide mainly due to their use in the transport sector.

1.5 World Crop Stubble Situation

The most widespread crops are cereals, rice and corn, which are mainly produced for feed and food, and generate a final residue of a lignocellulosic nature. Although a considerable amount of this waste is consumed in traditional uses, large volumes were left unused. Lignocellulosic biomass refers to cereal straw made up mainly of cellulose, hemicellulose and lignin, representing 90% of its dry weight, excluding the biomass of the cereal grain, which is mainly made up of proteins and sugars. Lignocellulosic biomass is the most abundant organic matter on earth, which has the advantage of being biodegradable and renewable. The world production of these staple crops grows simultaneously as the world population (see Fig. 1). Sugarcane is the most productive crop among staples, accounting for almost 2000 million tonnes of raw material per year. Cereal production is around 2800 million tonnes, according to the latest report from the Food and Agricultural Organization (FAO) of the U.N. Regarding the wheat, its production is close to 800 million tonnes.

Regarding rice, current production is above 500 million tonnes. As for the corn, production is around 1200 million tonnes. The USA stands out as the main producer

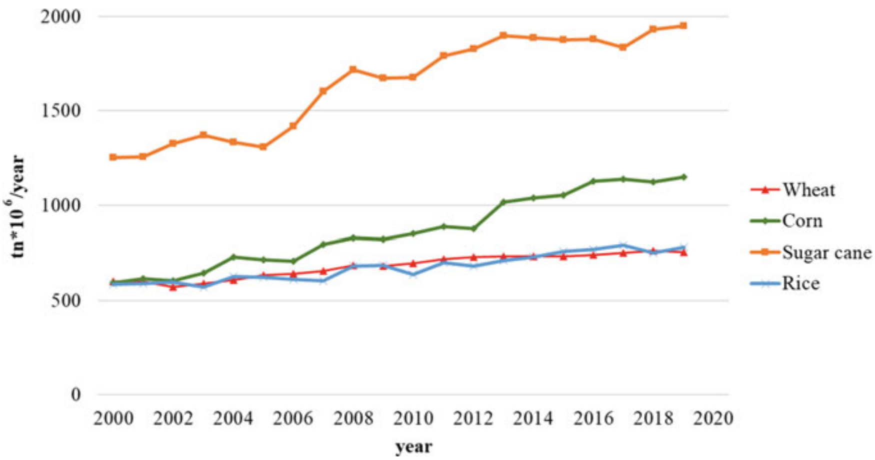

Fig. 1 Evolution in crop production

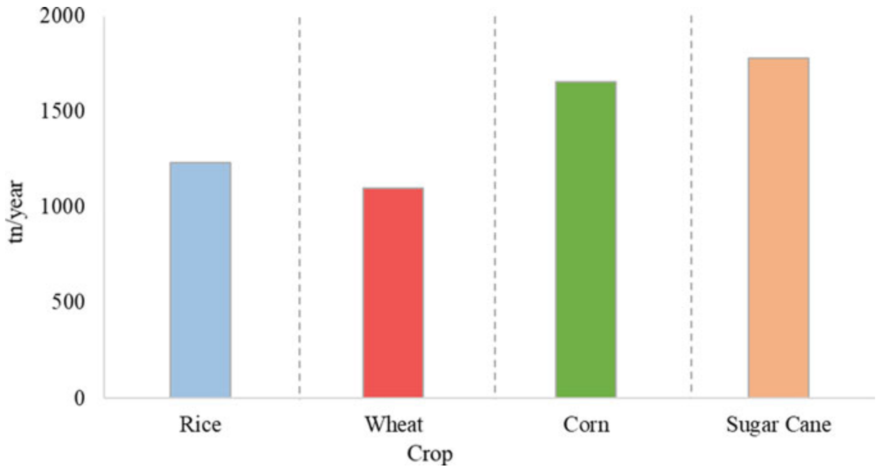

Fig. 2 Global stubble production of the main crops

of this crop. America is a continent with a large corn producing capacity; it produces more than 50% of the world's corn.

The amount of stubble produced by a crop is highly variable and depends on the type of soil, climate, cultivation techniques and technologies, etc. Production fluctuates depending on the agroecological areas. The straw produced can be calculated based on its harvest index (H.I.) (Eqs. 1 and 2). This index is obtained from the relationship between the grain's weight and the plant's total weight at maturity without considering the roots. This index may vary according to the crop's area, variety, and management.

$$\text{Harvest index (HI)} = \frac{\text{Grain weight (GW)}}{\text{Total plant weight except roots (PW)}} \quad (1)$$

The following relationship was used for the calculation:

$$\text{Straw production} = \frac{\text{Grain production } (t/\text{Ha})}{\text{HI}} \Delta(1 - \text{HI}) \quad (2)$$

The amount of stubble generated estimation per surface must be considered for the management planning and potential of the by-product (see Fig. 2).

2 Biofuels from Lignocellulosic Materials

The generation of biofuels from lignocellulosic materials, composed of cellulose, hemicellulose, and lignin, is of great interest due to its low cost and high availability.

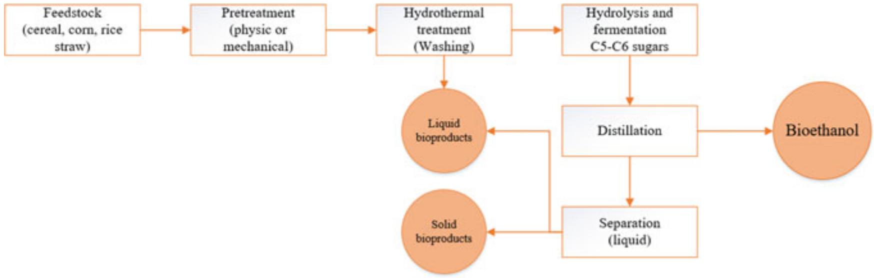

Fig. 3 Bioethanol process flow diagram

Thus, nowadays, different physicochemical and biological methods allow the use of the sugars that make up cellulose and hemicellulose and their transformation into biofuels such as biomethane, bioethanol or biobutanol. The biorefinery integrates the conversion processes of lignocellulosic biomass into biofuels, energy and chemical products, being of great interest as an alternative to fossil resources resulting in an economic and environmental positive impact.

2.1 *Bioethanol*

As can be seen in Fig. 3, after a first physical or mechanical pretreatment that seeks to reduce the particle size, a hydrolysis process is associated to reduce the crystallinity of the cellulose, the dissociation of the lignin–cellulose complex and the increased surface area to promote degradability by fermenting microorganisms.

Subsequently, sugars, acetic acid, furan derivatives, phenolic derivatives and various sugars can be found in the generated solution. On the latter, microorganisms selected for a specific molecule carry out fermentation of the sugars found (e.g. *S. cerevisiae* with the glucose molecule). In the last part of the process, distillation is carried out, in which the components or substances of the liquid mixture are separated with selective boiling and condensation. Bioethanol comes out of this last phase for its final use as a biofuel (Ingrao et al., 2021; Sarkar et al., 2012).

2.2 *Biomethane*

The production of biomethane is based on anaerobic digestion, a biological process in the absence of oxygen. Biogas is generated with a significant amount of biomethane, and another part of carbon dioxide and sulfuric acid based on bacterial activity. These last two are subsequently eliminated by upgrading, obtaining biomethane in 90–99% of the total volume.

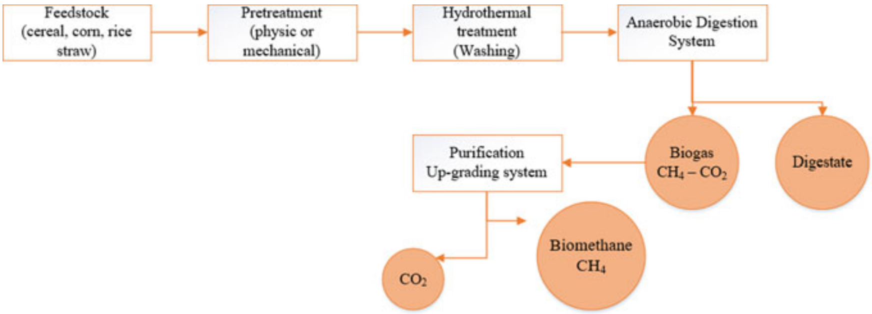

Fig. 4 Biomethane process flow diagram

In the process, there is a first pretreatment phase where hydrolysis accelerates the obtaining of monosaccharides, amino acids, and long-chain fatty acids. Subsequently, in the medium generated with the substrate mixture with bacterial inoculum, the hydrolysis and acidogenesis phase takes place where H_2, CO_2, acetic acid and other short-chain fatty acids are obtained as by-products. The acetate at this point, under the action of methanogenic archaea, forms methane, CO_2 and H_2S; these last two compounds decrease the calorific power of the biogas and prevent its use as biofuel in vehicles (Prussi et al., 2019). Different technologies can be used for its elimination, such as pressure water washing, chemical washing, PSA adsorption systems, membrane separation, organic solvent washing, cryogenic separation and biogas photosynthetic enhancement technology with microalgae (Rodero et al., 2019).

In the anaerobic digestion process, a liquid organic waste called digestate is also generated as bio compost. A diagram of this simplified process is shown in Fig. 4.

2.3 *Biobutanol*

In this process, an ABE fermentation (acetone–butanol–ethanol fermentation) occurs, characterized by bacterial activity to produce acetone, n-butanol and ethanol from carbohydrates embodied in the lignocellulosic biomass.

Two different stages are present in the ABE fermentation: acidogenesis, where there is rapid cell growth, and bacteria produce acetic acid, butyric acid, and CO_2 and from sugars generated in the previous phase; and a second phase, solventogenesis, where cell growth reaches a stationary phase, and organic acids are assimilated again, producing the ABE products: acetone, butanol and ethanol in the usual ratio of 3:6:1. (Niemisto, 2013; Liu et al., 2011; Xiros, 2017). The products of this fermentation are generally acetone, butanol, ethanol, acetic acid, butyric acid, hydrogen and carbon dioxide (Meramo, 2020; Jones & Wood, 1986; Ranjan, & Moholkar, 2012) (see Fig. 5).

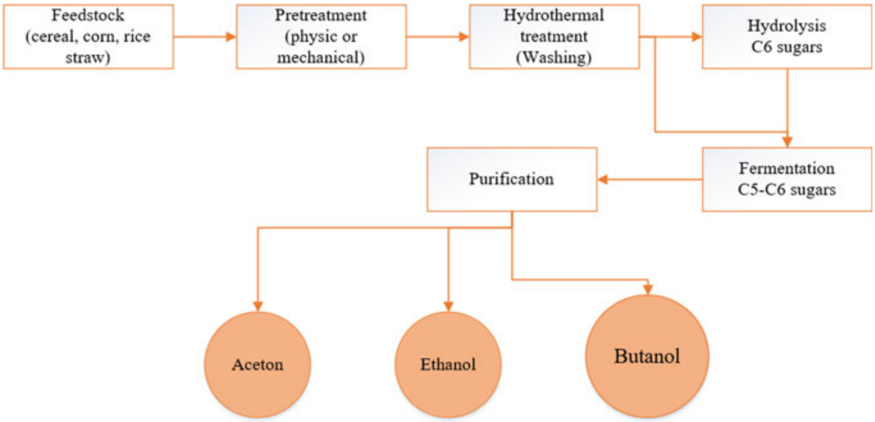

Fig. 5 Biobutanol process flow diagram

2.4 *Pretreatments*

Lignocellulose has low solubility in water and is very resistant to decomposition, which difficult the use of the monosaccharides. This fact has led to the research of chemical and biological methods that accelerate the hydrolysis of lignocellulose and the accessibility of these sugars Kim et al., (2016). The methods require a large amount of water and reagents (strong acids or bases), as well as high-temperature conditions. In contrast, biological methods do not require reagents or large amounts of water and can be carried out at room or slightly higher temperatures. The enzymatic hydrolysis processes are biological methods widely used at the industrial level. Pretreatments allow cellulose hydrolysis yields to increase from less than 20% of theoretical yields to values greater than 90% and are essential for better energy use (Lynd, 1996). Lignocellulosic materials are attractive due to their high availability in various climates and locations, which is why there are currently physicochemical and biological methods for its transformation into value-added products such as biofuels (e.g. biogas or bioethanol).

There are many techniques commercially available for substrate pretreatment. It depends mainly on the type of substrate. The most common treatments are thermal, chemical, physical/mechanical, ultrasonic, microwave, biological and metal addition methods. For the lignocellulosic raw material (wheat, corn and rice stubble), the most effective techniques resulting in considerable increases in biomethane production are depicted in Fig. 6 (Chandra et al., 2012; Fu et al., 2015; Gallegos et al., 2017; Hjorth et al., 2011; Kainthola et al., 2019; Kong et al., 2018; Mancini et al., 2016; Patil et al., 2016; Schroyen et al., 2014; Sharma et al., 1988; Song et al., 2014; Wyman et al., 2018).

During the last years, there have been many studies related to the hybridization of more than one pretreatment, and it has been observed that the processes optimize the

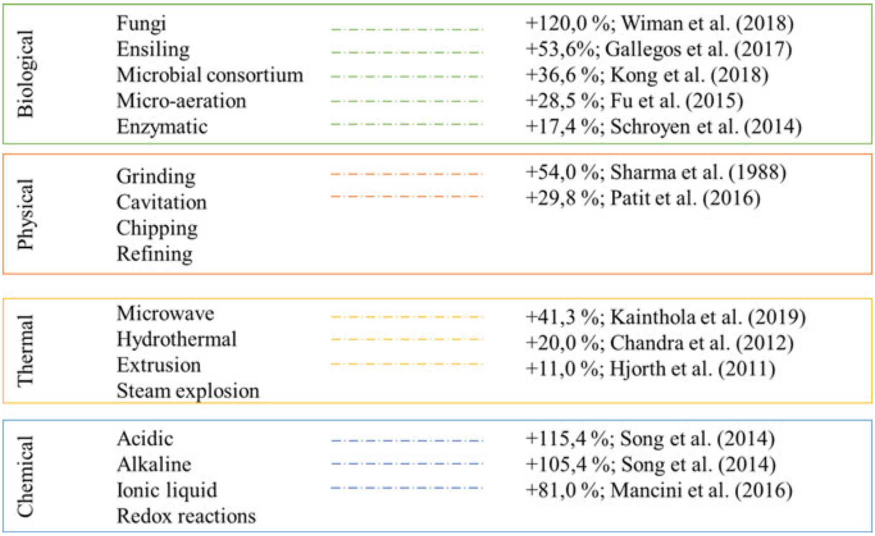

Fig. 6 Classification of pretreatments for lignocellulosic material

use of chemicals and energy. In addition, it has been reported that methane production improvement combines pretreatments.

3 Case Study

The potential energy production in biofuel was calculated considering 1 m^3 of common agricultural wastes: cereal straw, rice and corn stubble. These substrates were evaluated as feedstock for biomethane production through anaerobic digestion and bioethanol or biobutanol through alcoholic and ABE fermentation, respectively. An economic estimation from the potential energy generated (kWh) or distance (km) covered in the case of each substrate and type of biofuel is presented.

The methodology for the study is based on three phases for the final economic evaluation in each biofuel production process (see Fig. 7). The first phase consists of calculating the potential of each substrate, taking into account the chemical composition and physical features as well as the transformations required. The second phase consists of estimating energy output and input, respectively. According to previous studies, energy consumption was estimated based on the parameter Energy Return on Investment (EROI). In the third phase, there is an energy balance that is used for economic quantification.

Fig. 7 Methodology for the study case proposed

3.1 Characterization of Substrates

Each substrate's physical and chemical characteristics are quite similar, although slight variations are possible depending on weather, density or hemicellulose, cellulose lignin and ash content. This fact could be reflected in the result (Wiselogel et al., (1996). Average values have been considered for each case since these parameters depend largely on numerous environmental factors such as humidity, temperature and light. Table 1 shows a reference value for the main parameters.

The density and humidity data of the studied substrates, as well as the chemical composition data of the substrates, have been obtained from the following references: (Emami et al., 2014; Lawther et al., 1996; Saad, 2012) for cereal straw; (Ishii & Furuichi, 2014; Zhang et al., 2013) for rice straw; and (Viamajala et al., 2007) for corn stubble.

The density of each residue is slightly different; the average value for cereal straw is 0.17 kg / l, rice straw is 0.15 kg/l, and corn straw is 0.13 kg/l. The residue with the highest cellulose content is cereal straw 60.16 kg/m^3, followed by rice straw 51.52 kg/m^3 and finally corn straw 43.82 kg/m^3. The hemicellulose content is similar between cereal straw and corn with 45.12 kg/m^3 and 45.26 kg/m^3, respectively, rice straw is lower with 39.74 kg/m^3. Considering the difference between crops, it can be observed that the data are quite similar since there are no significant variations

Table 1 Characterization of substrates

	Cereal straw	Rice straw	Corn straw
Volume	1 m^3	1 m^3	1 m^3
Straw density	0.17 kg/L	0.15 kg/L	0.13 kg/L
Mass	170 kg	150 kg	130 kg
Humidity	6%	8%	18%
Cellulose content	60.16 kg	51.52 kg	43.82 kg
Hemicellulose content	45.12 kg	39.74 kg	45.26 kg
Lignin content	31.58 kg	33.12 kg	6.96 kg

in chemical composition, except with corn stubble, which contains a lower cellulose value, which ultimately results in less bioenergy production.

3.2 Transformation of Cellulose and Hemicellulose in Final Bioenergy Products.

Once the content of transformable organic materials was estimated, the potential production of biofuel was calculated. Previously reported studies have been taken as a reference in which the processes were analysed considering the net energy production. As presented in the work of Hall et al. (2011), who studied the processes for obtaining biofuels using the parameter EROI, the result could differ depending on the processes chosen for biofuels production. In the present work, lignocellulosic substrates have been considered a secondary by-product within the main agricultural activity, and therefore, consumption involved in grain (food) production has been considered zero, following the approach described by Kim and Dale, (2005). For the biofuel production process calculations, the following stoichiometric equations have been considered (Deublein & Steinhauser, 2008).

Hemicellulose is transformed into xylose, glucose and other sugars after pretreatment:

$$\text{Hemicellulose} \rightarrow (C_5H_{10}O_5)+(C_6H_{12}O_6) + \text{other sugars} \tag{3}$$

Cellulose after the hydrolytic action of endoglucanases, cellobiohydrolases and glucosidases is transformed to glucose

$$(C_6H_{10}O_5)\ 2n \rightarrow n(C_{12}H_{22}O_{11}) \rightarrow 2n(C_6H_{12}O_6) \tag{4}$$

These products are the precursors of ethanol after fermentation and distillation:

$$3(C_5H_{10}O_5) \rightarrow 5(C_2H_5OH) + 5CO_2 \tag{5}$$

$$(C_6H_{12}O_6) \rightarrow 2(C_2H_5OH) + 2\ CO_2 \tag{6}$$

In the case of ABE fermentation, the following transformations take place:

$$(C_6H_{12}O_6) \rightarrow (CH_3COCH_3)(\text{Acetone}) + 3\ CO_2 + 4\ H_2 \tag{7}$$

$$(C_6H_{12}O_6) \rightarrow (C_4H_9OH)(\text{Butanol}) + 2\ CO_2 + H_2O \tag{8}$$

$$(C_6H_{12}O_6)\text{®}2(C_2H_5OH)(\text{Ethanol}) + 2\ CO_2 \tag{9}$$

For biomethane obtention, there are reactions different because the process is based on anaerobic digestion. We have the following transformations:

$$(C_6H_{12}O_6)\ n \rightarrow 3n\ (CH_4)(\text{biomethane}) + 3n\ (CO_2) \tag{10}$$

3.3 Energy Produced and Economic Revenues

The energy balance and economic evaluation were based on different EROI studies in which energy involved in the whole process was considered. This reflects the energy contained in the form of biofuel considering the raw material (in this case, cereal, corn and rice stubble) and the amount of energy that is necessary to transform this resource. An energy analysis has been carried out for each biofuel and each waste substrate chosen to obtain it.

There are large differences between previous works published in this matter, which leads to large differences in the calculated rates of return.

As previously explained, the consumption of the agricultural production process is excluded from energy balances, including the fuel consumed, machinery, electricity, fertilizers, irrigation, herbicides, seeds and various transports. Therefore, the collection of stubble in the field is regarded as starting point of the process.

In the input part, the theoretical potential has been considered a function of the density of the material, the humidity and the average content of cellulose, hemicellulose and lignin in percentage terms and their conversion rates to glucose after hydrolysis. Considering the inputs, the following results have been obtained taking 1 m^3 of the substrate as a common base point for each process (Table 2).

The table shows the final amount of net energy obtained in the three processes to obtain each of the biofuels studied, starting from 1 m^3 of the substrate, considering the energy generated as biofuel and the energy consumed in the production process.

In obtaining bioethanol, it produces more energy from cereal straw, obtaining 224.10 kWh; secondly, there is 206.15 kWh rice straw and 151.87 kWh corn straw. In obtaining biobutanol, the highest value was obtained through rice straw 47.10 kWh, secondly, was cereal straw 44.33 kWh and finally corn straw 36.02 kWh (Sun et al., 2019). In the biomethane process, the highest amount of energy generated was obtained through corn straw 121.17 kWh, cereal straw 95.79 kWh, and the lowest value was obtained with rice straw 66.16 kWh (Gómez-Camacho et al., 2021).

Considering the energy produced with each waste, the distance travelled with each biofuel was calculated. Table 3 shows the economic data expressed in dollars that are obtained both from the sale of the net energy obtained and from the consumption in vehicles in the form of biofuel. This analysis revealed that bioethanol presents better economic performance.

The pretreatment technique continues to be the step with the highest energy consumption, as mentioned, critical for these substrates.

Figure 8 represents the net energy produced in biofuel for each waste.

Table 2 Energy production (inputs, output, net)

Energy (KWh)	Biomethane			Bioethanol			Biobutanol		
	Cereal straw	Rice straw	Corn straw	Cereal straw	Rice straw	Corn straw	Cereal straw	Rice straw	Corn straw
Output	304.0	210.0	384.6	5311	488.5	359.9	133.0	141.3	108.1
Input	208.3	143.8	263.4	307.0	282.4	208.0	88.7	94.2	72.0
Net	95.8	66.2	121.2	224.1	206.2	151.9	44.3	47.1	36.0

Table 3 Economic quantification of energy generated and distance travelled

		Wheat straw		Rice stubble		Corn stubble	
Biomethane	Energy production (KWh)	95.79	kWh	66.16	kWh	121.17	kWh
	km (vehicle)	162.91	km	112.52	km	206.06	km
	Energy production ($)	11.50	$	7.94	$	14.54	$
	km (vehicle) $	40.73	$	28.13	$	51.52	$
		Wheat Straw		Rice stubble		Corn stubble	
Bioethanol	Energy production (KWh)	224.10	kWh	206.15	kWh	151.87	kWh
	km (vehicle)	315.63	km	290.35	km	213.90	km
	Energy production ($)	26.89	$	24.74	$	18.22	$
	km (vehicle) $	20.78	$	19.11	$	14.08	$
		Wheat Straw		Rice stubble		Corn stubble	
Biobutanol	Energy production (KWh)	44.33	kWh	47.10	kWh	36.02	kWh
	km (vehicle)	68.31	km	72.58	km	55.50	km
	Energy production ($)	5.32	$	5.65	$	4.32	$
	km (vehicle) $	7.77	$	8.26	$	6.31	$

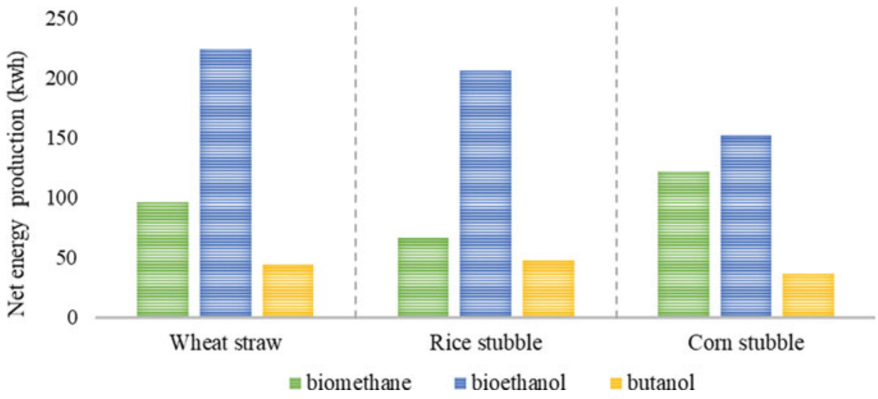

Fig. 8 Net energy production by biofuel and from 1 m^3 of substrate for cereal, for rice and corn stubble

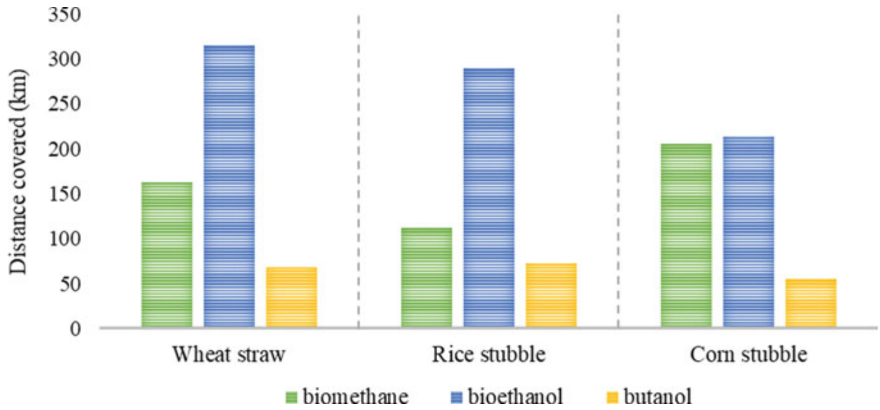

Fig. 9 Distance covered by biofuel starting from 1 m^3 of substrate for cereal, for rice and corn stubble

As shown in the figure, bioethanol presented a greater energy potential in a theoretical framework. On the other side, methane showed a lower value since a significant amount of organic matter is not degraded in the process. The following Fig. 9 represents the distance in km that could be travelled with biofuels produced by waste, replacing fossil fuels.

The longest distance travelled is obtained from cereal straw transformed to bioethanol with 315.63 km, in second place, with rice straw presented a value of 290.35 km and lastly, corn straw with 213.90 km. For biomethane, the greatest distance is achieved through corn straw, 206.06 km, followed by cereal straw, 162.91 km, and lastly, rice straw with 112.52 km. Biobutanol showed the lowest yields compared to the previous biofuels, with values of 72.58 km, 68.31 km and 55.50 km, for rice straw, cereal straw and corn straw, respectively.

For the economic analysis of the use of the straw by-product through the explained processes, each case's theoretical energy input and output have been taken, considering the study presented by Leung and Wang (2016). The next graph represents the income from the sale of biofuel (Fig. 10).

Biomethane production is economically more profitable since its price is higher than other biofuels. For the calculations, the average values of the current fuel market were used, taking a value of $ 1.15 per kg of biomethane for 0.79/l bioethanol and $ 0.91/l biobutanol. Data were taken from the Alternative Fuel Prices Report, July 2021 and the U.S. Energy Information Administration (US Department of Energy, 2021). 1 m^3 of corn straw will provide $ 51.52 if biomethane is produced, while $ 40.73 are obtained in the case of corn straw. Lowest biomethane revenue is obtained from d from rice straw, $ 28.13. In the case of bioethanol, $ 20.78 would be obtained with cereal straw, $ 19.11 with rice straw and $ 14.08 with corn straw. In the case of biobutanol, $ 8.26 would be obtained with rice straw, $ 7.77 with cereal straw and $ 6.31 with corn straw.

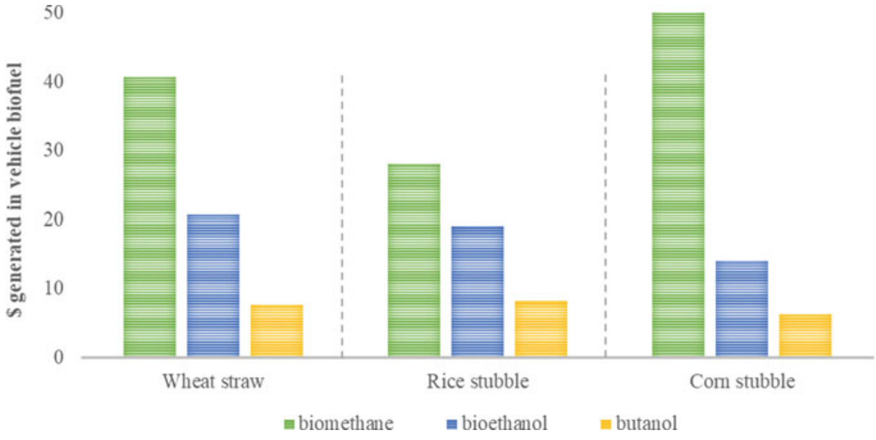

Fig. 10 Economic benefit from biofuel generated

Considering the inputs and outputs and taking the market price of the costs associated with each process, biomethane offers a better ratio per unit volume of stubble. The process is progressing, especially in the biogas improvement part, which makes this biofuel an alternative to conventional fossil fuels. In the same way, both ethanol and butanol also provide positive balances.

Figure 11 represents the money that would be obtained from the sale of energy, considering a value of 0.12 $/kWh as the price of energy, which corresponds to the average value of the current market.

In the case of biomethane, the following values are obtained: $ 14.54, $ 11.5, $ 7.94 for corn straw, cereal and rice, respectively. In the case of bioethanol, $ 26.89, $

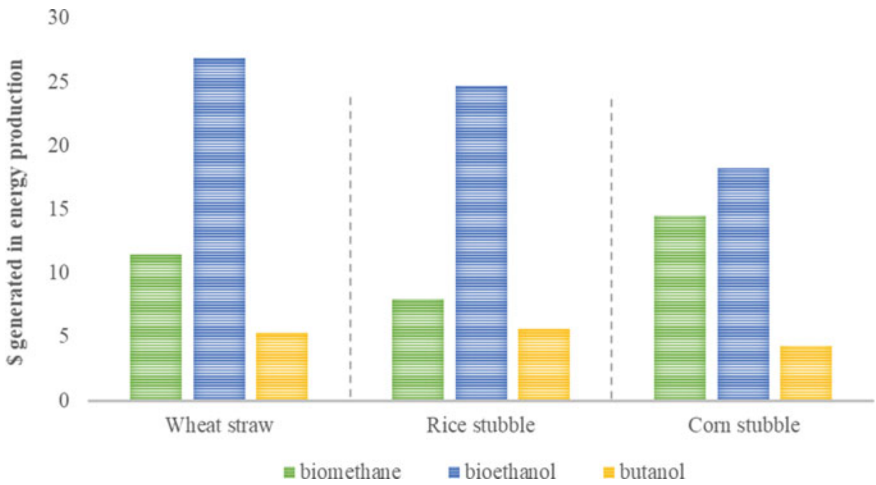

Fig. 11 Economic benefit for generated energy

24.74, $ 18.22 are obtained with cereal straw, rice and corn, respectively. In addition, in the case of biobutanol, $ 5.65, $ 5.32 and $ 4.32 are obtained with rice straw, cereal and corn, respectively.

Although the internal combustion engines consume a large amount of bioethanol (12 L/100 km), bioethanol delivers a longer distance travelled per unit of waste processed. The biomethane and biobutanol consumptions used in the calculations are 4 kg/100 km and 8 L/100 km, respectively.

An important benefit can be obtained from 1 m^3 of lignocellulosic residue in each pathway used. The three biofuels studied to contribute to positive economic balances. Biomethane, used as transport biofuel, presents the highest economic benefits. However, in terms of net energy production, bioethanol exhibits better performance. This situation can be changeable since prices fluctuate according to the energy and food markets.

4 The Legal Framework of Bioenergy and Its Connection with the Circular Economy – The European Initiative

The integration between climate and energy is unquestionable. Biomass energy has a fundamental role in the energy transition towards a renewable model to achieve, at the same time, a decarbonized and circular economy.

This section will study bioenergy and biomass fuels have been considered in the new Renewable Energy Directive (European Parliament, 2018) and their role in this economic transition.

4.1 Bioenergy and Circular Economy

The assessment impact of the Climate Objective Plan to reduce greenhouse gas emissions (GHGs) by 55%, at the same time, is necessary to reach a share of renewable energies by 2030 of between 38 and 40% [COM (2020) 562] (European Commission, 2020b). The main underlying idea is that the reduction of emissions depends on the expansion of renewable energies, which, as reflected in the Strategy for the Integration of the Energy System [COM (2020) 299 final], must be distributed geographically and flexibly integrate different energy vectors, while continuing to make efficient use of resources and avoiding pollution. The link between bioenergy and circular economy is related to the fact that the circular economy represents an alternative compared to a linear economy (extract-manufacture-use-throw away), consisting of keeping resources in use for as long as possible reducing and delaying the generation of waste. This was enshrined in the Commission Communication of 2 December 2015, under the title "Closing the circle: an E.U. action plan for the circular economy"

[COM (2015) 614 final] (European Commission, 2015), and it emerges with intensity through the European Green Pact that establishes a model of economic growth unrelated to the use of resources and where the circular economy is foreseen in several of the policies contemplated in the Pact, among which stands out "the mobilization of the industry in favor of a clean economy and circulate".

From a legal point of view, the circular economy is an instrumental principle to achieve later and lofty goals. There is no uniformity in its definition, and it has a transversal character with a clear transformative vocation that extends to a multiplicity of interrelated (but different) economic activities, such as production, consumption, waste management and markets for secondary raw materials (Alenza García, 2020).

The circular economy has had a greater prestige in the sustainable products sector and, especially, in the waste sector, since it determines how the principle of hierarchy is put into practice in its management, and it has given rise to legislative modifications - the tending perspective to the "zero waste" that changes the whole concept of waste to consider it as a resource (Nogueira López, 2020). It is important to emphasize that waste can be used for energy production, and, besides, the energy from residual biomass is considered renewable energy.

Indeed, the results obtained by the intermediate reports of the Action Plan are positive [COM (2017) 33 final] (European Commission, 2017), "Report on the implementation of the action plan for the circular economy" and [COM (2018) 29 final] (European Commission, 2018), "Framework monitoring for the circular economy"]. Nevertheless, by following the Green Deal and with the premise of greater ambition, a new Action Plan for the circular economy aiming at a cleaner and more competitive Europe was approved on 11 March 2020 [COM (2020) 98 final] (European Commission, 2020a), which is headed with the following sentence: "We only have one Earth, but in 2050 the world consumption will be equivalent to three planets".

To achieve greater circularity of the production processes in the industrial sector, it proposes, among other actions, to support the circular and sustainable biologically based sector through the application of the Action Plan for the bioeconomy [COM (2018) 763 final] and the incorporation of ecological technologies related to an environmental verification system, which will be registered as an E.U. certification mark. The circular economy has such importance that one of the Plan's proposals is, precisely, to adapt the E.U. legislation on waste to the circular economy and not the other way around, with the consequences that this entails. Also, aiming to the proper functioning of the internal market for secondary raw materials, the Commission will assess the possibility of developing the end-of-waste criteria in force at the E.U. level for certain waste streams. On the other hand, it promotes the role of circularity in future revisions of the national energy and climate plans and incorporates the circular economy's objective in the E.U. Taxonomy Regulation.

These measures may affect the development of bioenergy. However, it is a canvas on which one must begin to manoeuvre to achieve concrete results; otherwise, the circular economy would remain a very ambitious principle with little practical impact. However, the E.U. cannot act alone, but a global transition towards a circular economy is essential. Therefore, the Commission will propose a global alliance, and, at the same time, it will ensure that free trade agreements reflect its objectives.

References

Abedinia, O., Zareinejad, M., Doranehgard, M. H., Fathi, G., Ghadimi, N. (2019). Optimal offering and bidding strategies of renewable energy based large consumer using a novel hybrid robust-stochastic approach. *Journal of Cleaner Production*, *215*, 878–889. S0959652619300964. https://doi.org/10.1016/j.jclepro.2019.01.085

Acheampong, A. O., Boateng, E., Amponsah, M., & Dzator, J. (2021). Revisiting the economic growth–energy consumption nexus: Does globalization matter? *Energy Economics*, *102*. https://doi.org/10.1016/J.ENECO.2021.105472

Alenza García, J. F. (2020) Sepin (Ed.). *La economía circular en la política y en la normativa energética.*

American Council for an Energy-Efficient Economy. (2019). ACEEE's 2019 annual report.

American council for an energy-efficient economy. (CEEE). (2019). *State energy efficiency scorecard*.

Andersson, Ö., & Börjesson, P. (2021). The greenhouse gas emissions of an electrified vehicle combined with renewable fuels: Life cycle assessment and policy implications. *Applied Energy*, *289*. https://doi.org/10.1016/J.APENERGY.2021.116621, PubMed: 116621.

Bertheau, P. (2020). Assessing the impact of renewable energy on local development and the Sustainable Development Goals: Insights from a small Philippine island. *Technological Forecasting and Social Change*, *153*. https://doi.org/10.1016/j.techfore.2020.119919.

Chandra, R., Takeuchi, H., & Hasegawa, T. (2012). Methane production from lignocellulosic agricultural crop wastes: A review in context to second generation of biofuel production. *Renewable and Sustainable Energy Reviews, 16*(3), 1462–1476. https://doi.org/10.1016/j.rser.2011.11.035

Deublein, D., & Steinhauser, A. (2008). *Biogas from waste and renewable resources.* Wiley-VCH.

Dong, Z., Liu, J., Liu, B., Li, K., & Li, X. (2021). Hourly energy consumption prediction of an office building based on ensemble learning and energy consumption pattern classification. *Energy and Buildings*, *241*. https://doi.org/10.1016/j.enbuild.2021.110929, PubMed: 110929

Emami, S., Tabil, L. G., Adapa, P., George, E., Tilay, A., Dalai, A., Drisdelle, M., & Ketabi, L. (2014). Effect of fuel additives on agricultural straw pellet quality. *International Journal of Agricultural and Biological Engineering, 7*(2), 92–100. https://doi.org/10.3965/j.ijabe.20140702.011

European Economic and Social Committee. (2015) 614. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Closing the loop. An E.U. action plan for the circular economy. Com.

European Commission. (2017)/033. Report from the commission to the European Parliament, the Council, the European economic and social committee and the committee of the regions on the implementation of the circular economy action plan. Com.

European Commission. (2018)/029. Communication from the Commission to the European Parliament, the Council, the European economic and social committee and the committee of the regions on a monitoring framework for the circular economy. Com.

European Parliament. (2018). Directive (E.U.) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources.

European Biogas Association (2020). EBA statistical report 2020.

European Commission. (2020a). Communication from the Commission to the European Parliament, the Council, the European economic and social committee and the committee of the regions a new circular economy action plan for a cleaner and more competitive Europe. Com/2020a/98.

European Commission. (2020b). Communication from the Commission to the European Parliament, the Council, the European economic and social committee and the committee of the regions

Stepping up Europe's 2030 climate ambition Investing in a climate-neutral future for the benefit of our people. Com/2020b/562.
European statistics (Eurostat). (2021). *Energy statistics report*.
Fu, S. F., Shi, X. S., Xu, X. H., Wang, C. S., Wang, L., Dai, M., & Guo, R. B. (2015)[a]). Secondary thermophilic microaerobic treatment in the anaerobic digestion of corn straw. *Bioresource Technology, 186*, 321.e324. https://doi.org/10.1016/j.biortech.2015.03.053
Gallegos, D., Wedwitschka, H., Moeller, L., Zehnsdorf, A., & Stinner, W. (2017). Effect of particle size reduction and ensiling fermentation on biogas formation and silage quality of wheat straw. *Bioresource Technology, 245*, 216.e224. https://doi.org/10.1016/2017.08.137
Gómez-Camacho, C. E., Pirone, R., & Ruggeri, B. (2021). Is the anaerobic digestion (A.D.) sustainable from the energy point of view? *Energy Conversion and Management, 231*. https://doi.org/10.1016/j.enconman.2021.113857
Hall, C. A. S., Dale, B. E., & Pimentel, D. (2011). Seeking to understand the reasons for different energy return on investment (EROI) estimates for biofuels. *Sustainability, 3*(12), 2413–2432. https://doi.org/10.3390/su3122413
Hashemi, B., Sarker, S., Lamb, J. J., & Lien, K. M. (2021). Yield improvements in anaerobic digestion of lignocellulosic feedstocks. *Journal of Cleaner Production*, *288*. https://doi.org/10.1016/j.jclepro.2020.125447
Hjorth, M., Gränitz, K., Adamsen, A. P. S., & Møller, H. B. (2011). Extrusion as a pretreatment to increase biogas production. *Bioresource Technology, 102*(8), 4989–4994. https://doi.org/10.1016/j.biortech.2010.11.128
Hu, X. M., Ma, J. R., Ying, J., Cai, M., & Kong, Y. Q. (2021). Inferring future warming in the arctic from the observed global warming trend and CMIP6 simulations. *Advances in Climate Change Research, 12*(4), 499–507. https://doi.org/10.1016/j.accre.2021.04.002
International Agency for Energy. (IAE). (2021). *World energy outlook 2021*.
Jones, D. T., & Woods, D. R. (1986). Acetone–butanol fermentation revisited. *Microbiological Reviews, 50*(4), 484–524. https://doi.org/10.1128/mr.50.4.484-524.1986
Ingrao, C., Matarazzo, A., Gorjian, S., Adamczyk, J., Failla, S., Primerano, P., & Huisingh, D. (2021). Wheat-straw derived bioethanol production: A review of Life Cycle Assessments. *Science of the Total Environment, 781*. https://doi.org/10.1016/j.scitotenv.2021.146751, PubMed: 146751
International Bank for Reconstruction and Development (*International Bank for Reconstruction and Development. 2020*).
Ishii, K., & Furuichi, T. (2014). Influence of moisture content, particle size and forming temperature on productivity and quality of rice straw pellets. *Waste Management, 34*(12), 2621–2626. https://doi.org/10.1016/j.wasman.2014.08.008
Kainthola, J., Shariq, M., Kalamdhad, A. S., & Goud, V. V. (2019). Enhanced methane potential of rice straw with microwave assisted pretreatment and its kinetic analysis. *Journal of Environment Management, 232*, 188.e196. https://doi.org/10.1016/j.jenvman.2018.11.052
Kim, S., & Dale, B. E. (2005). Life cycle assessment of various cropping systems utilized for producing biofuels: Bioethanol and biodiesel. *Biomass and Bioenergy, 29*(6), 426–439. https://doi.org/10.1016/j.biombioe.2005.06.004
Kim, J. S., Lee, Y. Y., & Kim, T. H. (2016). A review on alkaline pretreatment technology for bioconversion of lignocellulosic biomass. *Bioresource Technology, 199*, 42–48. https://doi.org/10.1016/J.BIORTECH.2015.08.085
Kong, X., Du, J., Ye, X., Xi, Y., Jin, H., Zhang, M., & Guo, D. (2018). Enhanced methane production from wheat straw with the assistance of lignocellulolytic microbial consortium TC-5. *Bioresource Technology, 263*, 33–39. https://doi.org/10.1016/j.biortech.2018.04.079
Kurczyński, D., Łagowski, P., & Wcisło, G. (2021). Experimental study into the effect of the second-generation BBuE biofuel use on the diesel engine parameters and exhaust composition. *Fuel, 284*. https://doi.org/10.1016/j.fuel.2020.118982, PubMed: 118982
Lahiani, A., Mefteh-Wali, S., Shahbaz, M., Vo, X. V. (2021). Does financial development influence renewable energy consumption to achieve carbon neutrality in the USA? *Energy Policy*, *158*, 112524. S0301421521003943. https://doi.org/10.1016/j.enpol.2021.112524.

Lawther, J. M., Sun, R. C., & Banks, W. B. (1996). '*Fractional characterization of wheat straw lignin components by alkaline nitrobenzene oxidation and FT-IR spectroscopy' Ind. Crops production.*
Leung, D. Y. C., & Wang, J. (2016). An overview on biogas generation from anaerobic digestion of food waste. *International Journal of Green Energy, 13*(2), 119–131. https://doi.org/10.1080/15435075.2014.909355
Liu, X., Yan, Z., & Yue, Z.-B. (2011). Biogas. In M. Moo-Young (Ed.), Comprehensive biotechnology (2nd ed) (pp. 99–114). Academic Press.
Løkke, S., Aramendia, E., & Malskær, J. (2021). A review of public opinion on liquid biofuels in the E.U.: Current knowledge and future challenges. *Biomass and Bioenergy, 150*. https://doi.org/10.1016/j.biombioe.2021.106094, PubMed: 106094
Luo, Y., Zeng, W., Wang, Y., Li, D., Hu, X., & Zhang, H. (2021). A hybrid approach for examining the drivers of energy consumption in shanghai. *Renewable and Sustainable Energy Reviews, 151*. https://doi.org/10.1016/J.RSER.2021.111571, PubMed: 111571
Lynd, L. R. (1996). Overview and evaluation of fuel ethanol from cellulosic biomass: Technology, economics, the environment, and policy. *In Annual Review of Energy and the Environment, 21*(1), 403–465. https://doi.org/10.1146/annurev.energy.21.1.403
Mancini, G., Papirio, S., Lens, P. N. L., & Esposito, G. (2016). Solvent pretreatments of lignocellulosic materials to enhance biogas production: A review. *Energy and Fuels, 30*(3), 1892–1903. https://doi.org/10.1021/acs.energyfuels.5b02711
Meramo-Hurtado, S. I., González-Delgado, Á. D., Rehmann, L., Quiñones-Bolaños, E., & Mehrvar, M. (2020). Comparison of Biobutanol Production Pathways via Acetone-Butanol-Ethanol Fermentation Using a Sustainability Exergy-Based Metric. *ACS Omega, 5*(30), 18710–18730. https://doi.org/10.1021/acsomega.0c01656
Millo, F., Vlachos, T., & Piano, A. (2021). Physicochemical and mutagenic analysis of particulate matter emissions from an automotive diesel engine fuelled with fossil and biofuel blends. *Fuel, 285*. https://doi.org/10.1016/j.fuel.2020.119092, PubMed: 119092
National Hydrocarbon Information Center. (NHIC, 2020). *Annual report.*
Neves, S. A., Marques, A. C., & Fuinhas, J. A. (2017). Is energy consumption in the transport sector hampering both economic growth and the reduction of CO2 emissions? A disaggregated energy consumption analysis. *Transport Policy, 59*, 64–70. https://doi.org/10.1016/J.TRANPOL.2017.07.004
Niemisto, J., Saavalainen, P., Pongrácz, E., & Keiski, R. L. (2013). Biobutanol as a potential sustainable biofuel—Assessment of lignocellulosic and waste-based feedstocks. *Journal of Sustainable Development of Energy, Water and Environment Systems, 1*(2), 58–77. https://doi.org/10.13044/j.sdewes.2013.01.0005
Nogueira López, A. (2020). Cuadrar el círculo. El complejo equilibrio entre el impulso de la economía circular y unas reglas de mercado expansivas. https://www.researchgate.net/publication/338633187
Patil, P. N., Gogate, P. R., Csoka, L., Dregelyi-Kiss, A., & Horvath, M. (2016). Intensification of biogas production using pretreatment based on hydrodynamic cavitation. *Ultrasonics Sonochemistry, 30*, 79–86. https://doi.org/10.1016/j.ultsonch.2015.11.009
Pellegrini, L., Arsel, M., Orta-Martínez, M., Mena, C. F., & Muñoa, G. (2021). Institutional mechanisms to keep unburnable fossil fuel reserves in the soil. *Energy Policy, 149*. https://doi.org/10.1016/j.enpol.2020.112029
Prussi, M., Padella, M., Conton, M., Postma, E. D., & Lonza, L. (2019). Review of technologies for biomethane production and assessment of Eu transport share in 2030. *Journal of Cleaner Production, 222*, 565–572. https://doi.org/10.1016/j.jclepro.2019.02.271
Ranjan, A., & Moholkar, V. S. (2012). Biobutanol: Science, engineering, and economics. *International Journal of Energy Research, 36*(3), 277–323. https://doi.org/10.1002/er.1948
Rezaei, M., Amiri, H., & Shafiei, M. (2021). Aqueous pretreatment of triticale straw for integrated production of hemicellulosic methane and cellulosic butanol. *Renewable Energy, 171*, 971–980. https://doi.org/10.1016/J.RENENE.2021.02.159

Rodero, M. D. R., Lebrero, R., Serrano, E., Lara, E., Arbib, Z., García-Encina, P. A., & Muñoz, R. (2019). Technology validation of photosynthetic biogas upgrading in a semi-industrial scale algal-bacterial photobioreactor. *Bioresource Technology, 279*, 43–49. https://doi.org/10.1016/j.biortech.2019.01.110

Saad. (2012). Physical properties of wheat straw varieties cultivated under different climatic and soil conditions in three continents. *American Journal of Engineering and Applied Sciences, 5*(2), 98–106. https://doi.org/10.3844/ajeassp.2012.98.106

Sandoval-García, E., Matsumoto, Y., & Sánchez-Partida, D. (2021). Data and energy efficiency indicators of freight transport sector in Mexico. *Case Studies on Transport Policy, 9*(3), 1336–1343. https://doi.org/10.1016/J.CSTP.2021.07.007

Sarkar, N., Ghosh, S. K., Bannerjee, S., & Aikat, K. (2012). Bioethanol production from agricultural wastes: An overview. *Renewable Energy, 37*(1), 19–27. https://doi.org/10.1016/j.renene.2011.06.045

Sarker, S., Lamb, J. J., Hjelme, D. R., & Lien, K. M. (2019). A Review of the Role of Critical Parameters in the Design and Operation of Biogas Production Plants. *Applied Sciences, 9*(9), 1915. https://doi.org/10.3390/app9091915

Schroyen, M., Vervaeren, H., Van Hulle, S. W. H., & Raes, K. (2014). Impact of enzymatic pretreatment on corn stover degradation and biogas production. *Bioresource Technology, 173*, 59–66. https://doi.org/10.1016/j.biortech.2014.09.030

Scovronick, N., & Wilkinson, P. (2013). The impact of biofuel-induced food-price inflation on dietary energy demand and dietary greenhouse gas emissions. *Global Environmental Change, 23*(6), 1587–1593. https://doi.org/10.1016/J.GLOENVCHA.2013.09.013

Sharma, S. K., Mishra, I. M., Sharma, M. P., & Saini, J. S. (1988). Effect of particle size on biogas generation from biomass residues. *Biomass, 17*(4), 251–263. https://doi.org/10.1016/0144-4565(88)90107-2

Song, T. S., Wu, X. Y., & Zhou, C. C. (2014). Effect of different acclimation methods on the performance of microbial fuel cells using phenol as substrate. *Bioprocess and Biosystems Engineering, 37*(2), 133–138. https://doi.org/10.1007/s00449-013-0975-6

Song, C., Zhang, C., Zhang, S., Lin, H., Kim, Y., Ramakrishnan, M., Du, Y., Zhang, Y., Zheng, H., & Barceló, D. (2020). Thermochemical liquefaction of agricultural and forestry wastes into biofuels and chemicals from circular economy perspectives. *Science of the Total Environment, 749*, 141972. https://doi.org/10.1016/j.scitotenv.2020.141972

Sun, S. N., Chen, X., Tao, Y. H., Cao, X. F., Li, M. F., Wen, J. L., Nie, S. X., & Sun, R. C. (2019). Pretreatment of Eucalyptus urophylla in γ-valerolactone/dilute acid system for removal of non-cellulosic components and acceleration of enzymatic hydrolysis. *Industrial Crops and Products, 132*, 21–28. https://doi.org/10.1016/J.INDCROP.2019.02.004

United Nations. (2021). *World population prospects*.

United States Department of Energy. (2021). *Alternative fuel price report*.

Viamajala, S., Selig, M. J., Vinzant, T. B., Tucker, M. P., Himmel, M. E., McMillan, J. D., & Decker, S. R. (2007). Catalyst transport in corn Stover internodes. In *Twenty-Seventh Symposium on Biotechnology for Fuels and Chemicals*, pp. 509–527. https://doi.org/10.1007/978-1-59745-268-7_42

Víctor, R.-P. (2013). Sistema de estimación, certificación y aprobación de reservas de hidrocarburos en México; análisis de desempeño. *Ingeniería, Investigación y Tecnología, 14*(3), 451–460. https://doi.org/10.1016/S1405-7743(13)72257-1

Wiselogel, A., Tyson, S., & Johnson, D. (1996). Biomass feedstock resources and composition. In *Handbook on bioethanol: Production and utilization applied energy technology*, pp. 105–118).

Wyman, V., Henríquez, J., Palma, C., & Carvajal, A. (2018). Lignocellulosic waste valorization strategy through enzyme and biogas production. *Bioresource Technology, 247*, 402–411. https://doi.org/10.1016/j.biortech.2017.09.055

Xiros, C., Janssen, M., Byström, R., Børresen, B. T., Cannella, D., Jørgensen, H., Koppram, R., Larsson, C., Olsson, L., Tillman, A., & Wännström, S. (2017)Toward a sustainable biorefinery using high-gravity technology. *Biofuels, Bioproducts and Biorefining. Roberth and Borresen and Cannella, 11*(1), 15–27. https://doi.org/10.1002/bbb.1722

Yu, Y., Wu, J., Ren, X., Lau, A., Rezaei, H., Takada, M., Bi, X., & Sokhansanj, S. (2021). Steam explosion of lignocellulosic biomass for multiple advanced bioenergy processes: A review. *Renewable and Sustainable Energy Reviews, 154*. https://doi.org/10.1016/j.rser.2021.111871, PubMed: 111871

Zhang, Y., Ghaly, A. E., & Li, B. (2013). Physical properties of rice residues as affected by variety and climatic and cultivation onditions in three continents. *American Journal of Applied Sciences, 9*(11), 1757–1768. https://doi.org/10.3844/ajassp.2012.1757.1768

Zhu, Y., Zhai, Y., Li, S., Liu, X., Wang, B., Liu, X., Fan, Y., Shi, H., Li, C., & Zhu, Y. (2021). Thermal treatment of sewage sludge: A comparative review of the conversion principle, recovery methods and bioavailability-predicting of phosphorus. *Chemosphere*, 133053. https://doi.org/10.1016/j.chemosphere.2021.133053