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Energy in agriculture in Brazil

Energia na agricultura no Brasil

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ABSTRACT - Historically, agriculture has been a large contributor to the global green house gas emissions due to the use of fossil fuel-powered machinery during the production cycle. In recent years, there has been a pressing need to replace fossil fuel consumption given the increasing threats associated with climate change. This paper presents a review of the latest studies published in the field of energy in the agricultural sector, with a specific focus on Brazil. Based on the research trends observed over the last few years (2012-2020), findings tend to point towards improving current practices rather than studying alternatives to fossil fuel consumption, with recent publications (2020-2021) continuing this trend, primarily via market- and indicator-based studies. As reported in the reviewed literature, tobacco production has the largest energy demand, while wheat, sugarcane, and eucalyptus production have the greatest ethanol production potential. Both rapeseed and jatropha production share greater biodiesel production potential than soybean. Of the 14 crops considered in this study, four had a negative energy surplus: tobacco, orange, rice, and cotton.

Key words: Agriculture. Energy. Trend. Recent development. Review.

RESUMO - Historicamente, a agricultura tem contribuído muito para as emissões globais de gases de efeito estufa devido ao uso de máquinas movidas a combustíveis fósseis durante o ciclo de produção. Nos últimos anos, houve uma necessidade urgente de substituir o consumo de combustível fóssil devido às crescentes ameaças associadas às mudanças climáticas. Este artigo apresenta uma revisão dos últimos estudos publicados na área de energia no setor agrícola, com enfoque específico no Brasil. Com base nas tendências de pesquisa observadas nos últimos anos (2012-2020), os resultados tendem a apontar para a melhoria das práticas atuais ao invés de estudar alternativas para o consumo de combustíveis fósseis, com publicações recentes (2020-2021) que continuam essa tendência, principalmente por meio do mercado. e estudos baseados em indicadores. Conforme relatado na literatura revisada, a produção de fumo apresenta a maior demanda de energia, enquanto a produção de trigo, cana-de-açúcar e eucalipto apresenta o maior potencial de produção de etanol. Tanto a produção de colza quanto a de jatropha compartilham um potencial maior para a produção de biodiesel do que a soja. Das 14 safras consideradas neste estudo, quatro apresentaram superávit energético negativo: fumo, laranja, arroz e algodão.

Palavras-chave: Agricultura. Energia. Tendência. Desenvolvimento recente. Reveja.

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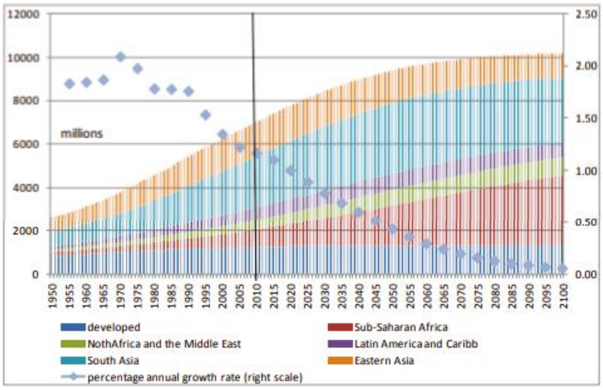
INTRODUCTION

Over the last few decades, the global population has increased significantly. According to the most recent estimate of the United Nations (UN), there are now 7.7 billion inhabitants, and projections are set to increase to more than 9.7 billion by 2050. Most of the population increase is expected to take place in developing countries, specifically countries located in sub-Saharan Africa and Asia. On the other hand, developed countries, like most of the western European countries, will show a steady, if not declining, trend in population growth (FAO, 2012), as shown in (Figure 1).

Figure 1 - Expected population growth and amount of people by region until 2100 (FAO, 2012)



In addition to the anticipated population growth, the demand for resources will also increase. To satisfy the growing food demand, there will need to be increases in productivity and structural changes within the agricultural sector (DÁNIEL FRÓNA, 2019). Due to the rising food demand caused by population growth, agricultural land use has increased significantly across most continents over the last 20 years, primarily leading to a reduction in forest area.

The global land area is around 13.2 billion ha, of which 12% (1.6 billion ha) is currently being used for the cultivation of agricultural crops; further, 28% (3.7 billion ha) is covered by forest, and 35% (4.6 billion ha) comprises grasslands and woodland ecosystems (FAO; EARTHSCAN, 2011). According to the Food and Agriculture Organization (FAO) (FAO, 2020b), Asia's agricultural land is the largest when compared to the continent's extension, covering around 54% of its total surface. This is followed by Oceania with 45%, Africa with 38%, the Americas with 30% and, lastly, Europe with 21% of available agricultural land. Land use change varied among the different continents as well; Africa and the Americas reported a change in forest land to agricultural land over the past 20 years, contributing to the increased crop production needed to meet the demands across the continent, but at a higher environmental cost (TILMAN *et al.*, 2011). Countries with the highest deforestation rate in terms of percentage of area were Paraguay (16%), Nicaragua (15%), and Cambodia (14%), converting most of their lands for other uses. In terms of area, Brazil registered the loss of 52 million ha of forest in favor of agricultural land, marking the highest amount of deforested area during this period.

According to the FAO (FAO, 2019), in 2017, the most frequently produced crops, worldwide were sugar cane (1,841,528 thousand tons), maize (1,134,747 thousand tons), wheat (771,719 thousand tons), rice (769,658 thousand tons) and potatoes (388,191 thousand tons).

Global population growth also entails increase energy demands, whether for heat, transportation, or electricity. The increase in energy demands around the world has been rising together with the population growth and development of numerous countries. According to data from the International Energy Agency (IEA), it was noted how by 2015, the global demand for energy was almost 10 million ktoe (29.6% in industrial, 28.6% in transport, 21.2% in residential, 2.1% for agricultural, and the remaining 18.5% used for commercial and other non-specified sectors). Traditionally, energy is generated by processing fossil fuels like coal, natural gas, and oil which, together, covered around 79% of the current global demand. During the transformation process, fossil fuels emit different pollutants like ash, sulfur oxides, nitrogen oxides, and volatile organic compounds into the atmosphere (CHMIELEWSKI, 2014). Furthermore, electricity production from fossil fuels not only pollutes the atmosphere, but also affects the water and soil during extraction (GAETE-MORALES *et al.*, 2019). There are some traditional renewable sources that contribute to the generation of energy worldwide, the most notable among which are hydropower (covering about 2.5% of global demand) and biofuels (covering around 9.5% of the global energy demand). The latter is used mostly for heating purposes in developing countries that do not have access to modern cooking fuels (WORLD BIOENERGY ASSOCIATION, 2019). Wind and solar energy have recently shown rapid development around the world given their use for electricity generation; however, their share of the global market is still minimal.

Food and agriculture are two major sectors that have been growing in association with the increase in the human population. This expansion has also affected global energy consumption through the industrialization of agriculture and large-scale production. As of 2018, the energy demand in the agricultural sector represented 2.1% of the total global energy demand, increasing from 149,194 ktoe worldwide in 2000 to 214,719 ktoe in 2018 (IEA, [*s. d.*]).

Land use for food crops growth is mostly determined by global diet and agricultural yields, meaning that the more yield the agricultural land has, the less land is required to produce certain crops. In this way, energy crops face competition for land use (POPP *et al.*, 2014), limiting the availability of land and water for production. The dependency on fossil fuels in the agricultural food industry could be reduced by applying the circular economy approach, as some countries have been investigating methods that can convert waste generated during the harvesting of several crops as possible sources of energy for the agricultural sector (ZAPALOWSKA; BASHUTSKA, 2019).

Located East of South America, with an area of 8,515,759 km^2, Brazil is the largest and most populated country in the continent. It is considered by the World Bank (THE WORLD BANK, 2020) as an upper-middle income country with an emerging economy. Furthermore, as stated by the OECD (OECD, 2018), Brazil's strong growth and social progress over the past decades have made it one of the world's leading economies. Its economy is mostly based on agriculture, industry, and a wide range of services. Considered as one of the most important countries in agriculture production, Brazil is the largest producer of sugarcane, soybeans, coffee and other crops. This is why its agricultural land comprises around 28.7% of the country's total surface (RAMOS; BALBUENO; PINHEIRO, 2017).

In a country like Brazil - which not only represents the most populated country in South America, but is also characterized by its rapidly developing economy - there is a demand for a large quantity of energy supply. Considered as one of the countries with the highest renewable energy shares, Brazil's energy matrix is comprised of approximately 46.2% of renewable energies and 53.8% (INTERNATIONAL ENERGY AGENCY (IEA), 2020) of other sources, ranging from fossil fuel to nuclear energy. Among the country's renewable energy sources, biofuels/biomass and hydropower are the main sources of energy used, covering 25% and 12% of the total demand, respectively. Furthermore, Brazil's share of wind, solar, and other renewable energy sources has increased from 5.9% in 2017 to 6.7% in 2018 (EPE, 2018).

Given this information, the purpose of the present paper is to identify the theoretical energy balance of the primary crops in Brazil, while further determining different energy crops that may be important within the Brazilian context. The next sections present a review of recently published articles. Data on the energy used in the agricultural sector, as well as the possible energy contained in residues, are compiled from the reviewed articles and used to identify the theoretical opportunities for energy extraction within the agricultural sector.

Bioenergy in Brazil

Considered as a highly important country in the global biomass market due to its vast production of crops like sugarcane, soja, and others, which are used in the production of biofuels and biomass, Brazil has a strong presence and holds great potential to generate energy from agricultural and organic wastes (WELFLE, 2017). Brazil's Ministry of Agriculture estimates that the agricultural and feedstock land expansion will increase significantly in the coming years, converting natural savannas and pasturelands in the country for these purposes (MINISTRY OF AGRICULTURE LIVESTOCK AND FOOD SUPPLY, 2006). Biofuels already play an important role in the Brazilian energy market. Brazil has the most competitive program for the development and production of biofuels, and it has the second largest ethanol industry worldwide (WELFLE, 2017). The reserves of cultivable area (excluding forests) are significant enough to produce biomass as a source of vegetable oils, which could be converted into biodiesel, considerably expanding Brazil's production without affecting the environment.

Studies suggest that the agricultural value added, as well as the resulting CO_2 emissions, have short- and long-run bidirectional causality. This means that a change in agricultural production would have immediate effects on emissions due to the intensive fossil fuel consumption in the sector (BEN JEBLI; BEN YOUSSEF, 2017; LIU; ZHANG; BAE, 2017). Similar, short-run Granger causal relationships have been described from non-renewables to emissions and agriculture, from economic growth to agriculture, and from agriculture to renewable energy (LIU; ZHANG; BAE, 2017). These estimates seem to indicate that an increase in renewable energy consumption in agriculture decreases the overall CO_2 emissions. Short-run causality from agriculture to gross domestic product (GDP), as well as long-run causality from GDP to agriculture seem to indicate that an increase in agricultural production has immediate impacts on economic growth. In the long run, economic growth can improve the development of the agricultural sector (BEN JEBLI; BEN YOUSSEF, 2017).

MATERIAL AND METHODS

The present study is comprised of several parts. First, a literature review of relevant publications was conducted. Then, based on the findings from the literature, data on the energy opportunities and energy demands of the Brazilian agricultural sector were extracted and compiled, as shown in Table 1. The values and units were averaged and homogenized to have a base of comparison (Table 2)**.** The fuel production potential was converted to GJ/ha using the productivity of each crop, as well as the ethanol and bio diesel energy content values of 19.8 MJ/L and 34.5 MJ/L, respectively.

In the first part of this study, the primary subjects of interest identified in the field were identified from the literature, and included the following: agricultural residues (PORTUGAL-PEREIRA *et al.*, 2015), ethanol, bio-refinery, bio-diesel (FAO, 2020a), crambe, sugarcane, bagasse, technical potential, boiler, co-generation, electrification (CARVALHO *et al.*, 2020), combustion, solar (OLIVEIRA *et al.*, 2018), family agriculture, life cycle assessment (LCA), energy demand (TIEPPO *et al.*, 2019), soybean (CAVALETT; ORTEGA, 2010; MACIEL *et al.*, 2015; TIEPPO *et al.*, 2019), land-use (LOSSAU *et al.*, 2015; LYRIO DE OLIVEIRA *et al.*, 2020), geographic information system (GIS), family farming (MAROUN; LA ROVERE, 2014; PORTE *et al.*, 2010; VOGT; ALBIERO; SCHMUELLING, 2018), indicator, agriculture (FENGLIN; JIN; GAOHUA, 2020), livestock, maize (FERREIRA *et al.*, 2018), biogas (PRADE; SVENSSON; MATTSSON, 2012), vinasse, eucalyptus (PIGHINELLI; SCHAFFER; BOATENG, 2018), hemp (KREUGER *et al.*, 2011; TEIXEIRA, 2020), lignin, economy, energy return on energy investment (EROI), energy balance (DENG *et al.*, 2015; PRADE; SVENSSON; MATTSSON, 2012), causality, market, methane, anaerobic digestion, sweet sorghum, projection, thermal, emission, wind, biomass, sustainability, performance, sugar, fuel consumption, waste, black liquor, wood, distillery, fruit bunch, palm oil, straw, gasifier (CHAVES *et al.*, 2016), beef tallow, field burning, torrefaction, rapeseed, canola, sunflower and cotton.

To identify the research trends over the last few years (see Figure 2), the fields of interest identified were cross-referenced with the 50 most cited publications per year during the period spanning 2012-2020. Publication selection was achieved through Scopus (SCOPUS, [*s. d.*]) and articles were chosen from peer-reviewed articles if they focused of agriculture, energy, and Brazil, and were published within the aforementioned time period. Throughout this period, the most frequently studied subjects that fell within the scope of this research were as follows: “sugar” (CERVI *et al.*, 2019; GALDOS *et al.*, 2013; GNANSOUNOU; VASKAN; PACHÓN, 2015; MANTOAM *et al.*, 2014; SILVA NETO; GALLO, 2021) with 95 instances; “emissions” with 86 instances;

Table 1 - Average production per crop, ratio of residue production and fuel conversion as reported in the literatures referenced

	AVERAGE PRODUCTION (CROP)			RESIDUE RATIO		CONVERSION RATIO			
	Value	Unit	Ref	Value	Ref	Value	Unit	Fuel	Ref
SUGARCANE			A						A
	73.5, 70, 85	t/ha	B	0.25	D	74.5, 60, 87 (92)	L/t (kg/t)		L
	(663.4)	(Mt/yr)	C	(0.22)	J	(92) [1.68]	[GJ/t]	Ethanol	B
			D						I
									C
RICE				0.2	D				
	13.9	Mt/yr	D	(1.49)	J				
				1.8	K				
SOYBEAN	2.4	t/ha	A	2.05	J	205	L/t (GJ/ha)	Bio-diesel	A
				(2.01)	K	(6.21)			I
COTTON				2.95	J				
				(2.81)	K				
CASSAVA	13.6	t/ha	A	0.2	J	137	L/t	Ethanol	A
				(1.11)	K				
PEANUT				2.52	K				
COFFEE				0.59	K				
COCONUT				1.26	K				

Continued Table 1

PALM OIL				0.38	K				
BEAN				1.45	K				
RYE	4.5	t/ha	E	1.61	K				
BARLEY	6	t/ha	E	1.48	K				
CORN	16.5 6 (16.5)	t/ha (Mt/yr)	D E	0.7 (1.42)	D J	0.32 (150) [8.61]	m^3/kg (GJ/ha) [GJ/ha]	Methane [Ethanol]	G M I
SORGHUM	9	t/ha	E	1.9	K				
OAT	4.2	t/ha	E	1.54	K				
WHEAT	4 (6.1)	t/haMt/yr	D	0.74 (1.42) 1.55	D J K	80 (7.71)	GJ/ha (GJ/t)	Ethanol	M I
CRAMBE	1.85	t/ha	N			300	L/t	Bio-diesel	N
TOBACCO				0.75	J				
ORANGE				0.5	J				
MILLET									
SORGHUM									
HEMP	12.4 (5.8-10.2)	t/ha (t/ha)	F G			0.22 (120) [2800]	m^3/kg (GJ/ha) [L/ha]	Methane [Ethanol]	G M F
EUCALYPTUS (WOOD CHIPS)	9.5 (16.5)	Mt/yr (t/ha)	D H	0.35	D	7.39	GJ/t	Ethanol	I
MILLET	6.3	t/ha yr	E						
RAPESEED	2.85	t/ha	I			40 (15.72)	GJ/ha (GJ/t)	Bio-diesel	M I
JATROPHA	4.5	t/ha	I			10.97	GJ/t	Bio-diesel	I

A: (FAO, 2020a) - B: (MAROUN; LA ROVERE, 2014) - C: (GALDOS *et al*., 2013) - D: (HORST; BEHAINNE; JUNIOR, 2017) - E: (ANDREA *et al*., 2014) - F: (KUGLARZ *et al*., 2014) - G: (PRADE; SVENSSON; MATTSSON, 2012) - H: (SMEETS; FAAIJ, 2010) - I: (DENG et al., 2015) - J: (FORSTER-CARNEIRO *et al*., 2013) - K: (PORTUGAL-PEREIRA *et al*., 2015) - L: (GNANSOUNOU; VASKAN; PACHÓN, 2015) - M: (KREUGER *et al*., 2011) - N: (BASSEGIO *et al*., 2016)

Table 2 - Averaged and homogenized data for crops with at least two data values (e.g. value for production and value for fuel conversion ratio)

				ETHANOL		BIODIESEL		METHANE		METHANE FROM VINASSE	
	Production	Unit	Residue ratio	Conversion ratio	Unit	Conversion ratio	Unit	Conversion ratio	Unit	Conversion ratio	Unit
SUGARCANE	76.17	t/ha	0.24	127.96	GJ/ha					18.87	GJ/ha
SOYBEAN	2.40	t/ha	2.03			6.21	GJ/ha				
CASSAVA	13.60	t/ha	0.66	36.89	GJ/ha					5.44	GJ/ha
CORN	16.50	t/ha	1.06	8.61	GJ/ha			150.00	GJ/ha	1.27	GJ/ha
WHEAT	4.00	t/ha	1.24	80.00						11.80	GJ/ha
CRAMBE	1.85	t/ha				19.15	GJ/ha				
HEMP	9.47	t/ha		55.44	GJ/ha			120.00	GJ/ha	8.17	GJ/ha
EUCALYPTUS (WOOD CHIPS)	16.50	t/ha	0.35	181.00	GJ/ha					26.69	GJ/ha
RAPESEED	2.85	t/ha				40.00	GJ/ha				
JATROPHA	4.50	t/ha				49.37	GJ/ha				

Figure 2 - Appearance of identified areas of interest in the fifty most cited publications during the period of 2012 to 2020

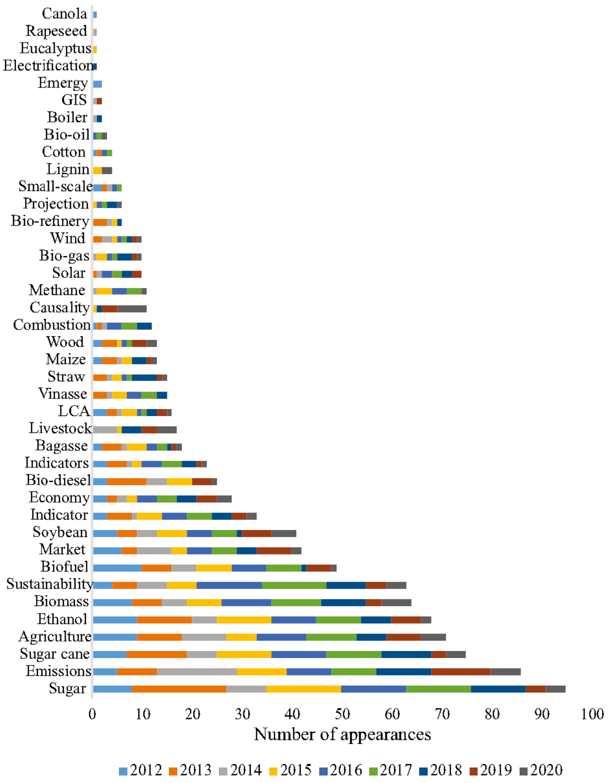
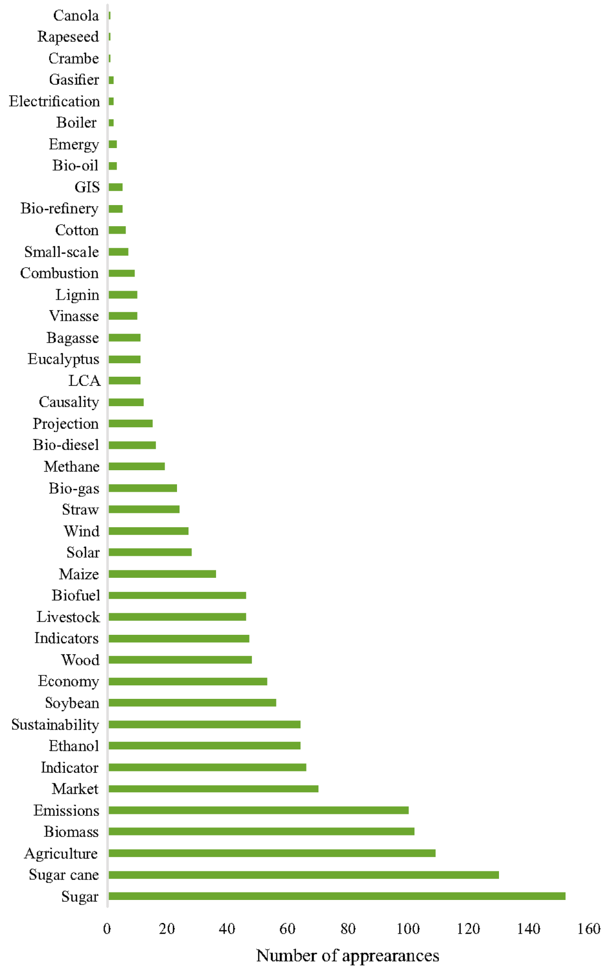


Figure 3 - Number of appearance of selected keywords in the 1,000 most recent accepted papers as per the latest search performed on 29.10.2020 (SCOPUS, [s. d.])



"sugarcane" (CERVI *et al.*, 2019; GALDOS *et al.*, 2013; MANTOAM *et al.*, 2014; SILVA NETO; GALLO, 2021) with 75 instances, "ethanol" (AZADI *et al.*, 2012; KUGLARZ *et al.*, 2014; MAROUN; LA ROVERE, 2014; RAMAN; GNANSOUNOU, 2014; REZENDE; RICHARDSON, 2017; SCHEIDL *et al.*, 2015; SOCCOL *et al.*, 2010) with 68 instances, "biomass" (ANDREA *et al.*, 2014; DA SILVA *et al.*, 2018; GALEMBECK, 2010; RAMAN; GNANSOUNOU, 2014; RIBEIRO; RODE, 2019; WELFLE, 2017) with 64 instances and "Sustainability" (GERALDES CASTANHEIRA *et al.*, 2014; SMEETS; FAAIJ, 2010; TAKAHASHI; ORTEGA, 2010) with 63 instances.

In addition to these trends, the 1,000 most recent publications (identified as of October 29, 2020, according to (SCOPUS, [*s. d.*])) were analyzed. The abstracts of these most recent publications were cross-referenced with the areas of interest identified in the previous steps to identify the latest points of focus (Figure 3) for research conducted in the Brazilian "energy in agriculture" sector.

"Sugar" was mentioned in 15.20% of the publications, "sugarcane" was mentioned in 13.00%, "agriculture" in 10.90%, "biomass" in 10.20% and "emissions" in 10.00%. "Ethanol" and "sustainability" were only mentioned in 6.40% of the articles, respectively. "Market" went from being the ninth most mentioned research topic in the period spanning 2012–2020, to being the sixth most mentioned, as it was featured in 7.00% of the 1,000 most recently published article.

RESULTS AND DISCUSSION

The averaged and homogenized data from Table 2 were compared with the energy demand required to grow 1 ha of the respective crop. Data gaps are observable in Table 2 and in Figure 4 to Figure 7**.** These findings reiterate the level of interest and research trends identified previously, noting that areas of greater interest have more data available.

Figure 4 to Figure 7 present the data available on the crops reported in the reviewed literature to identify the keywords used to uncover research trends. With respect to ethanol (Figure 4), eucalyptus appears to have the greatest potential per hectare. This can be explained by the amount of biomass growth in 1 ha of land. Following eucalyptus, sugarcane and wheat have the highest ethanol production potential. Hemp is a crop not currently grown in Brazil, but has great potential for ethanol production with 80 GJ/ha ethanol.

Currently, a large amount of the biodiesel produced in Brazil comes from soybean, despite the fact that its fuel potential per hectare is low, yet the amount harvested in Brazil is considerable enough to support production. The oil seeds crambe, rapeseed, and jatropha all have the potential for higher possible productivity per hectare, as well as higher biodiesel production potential (Figure 5). Data on the energy requirements to prepare the field, as well as to seed, maintain, and harvest the crop were unavailable in the reviewed literature, as the articles exploring Brazil as a case study have paid little attention to these aspects.

Figure 4 - Productivity of crop, energy demand and theoretical ethanol production

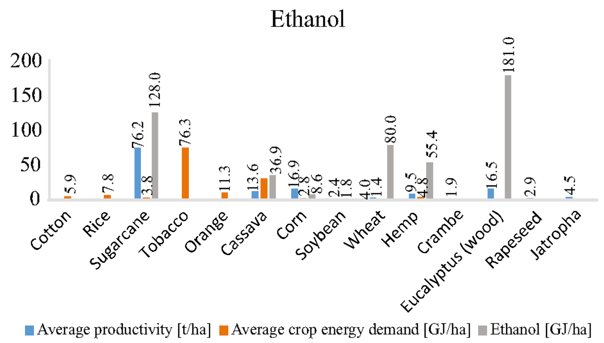


Figure 5 - Productivity of crop, energy demand and theoretical bio-diesel production

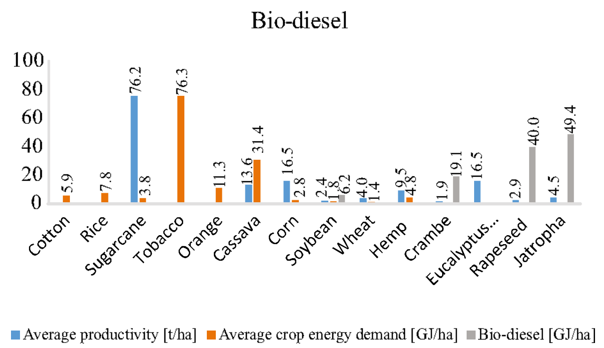


Figure 6 - Productivity of crop, energy demand and theoretical methane production

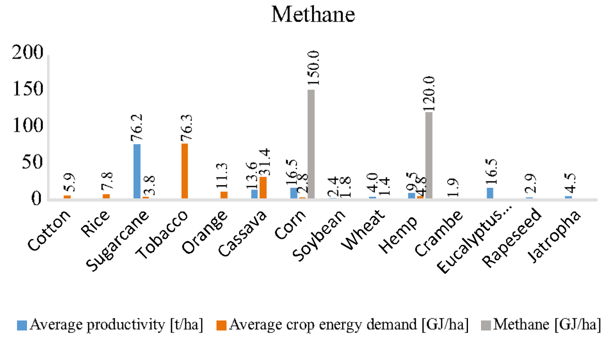
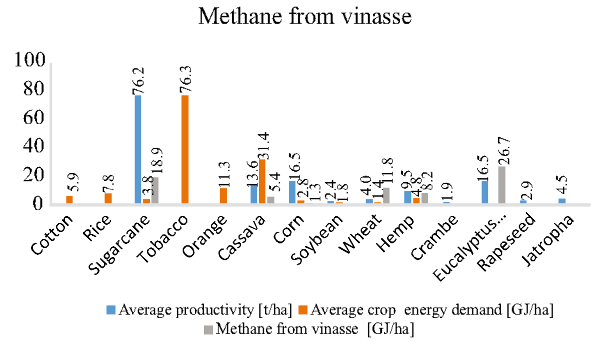


Figure 7 - Productivity of crop, energy demand and theoretical methane from vinasse production



Data on methane production were available for two crops (maize and hemp), only one of which is currently produced in Brazil. Of these two, maize has the biggest methane production potential, followed by hemp (Figure 6). Maize also has higher crop productivity and lower energy requirements than hemp, making it preferable for methane production.

Only one study (SILVA NETO; GALLO, 2021) of those reviewed addressed the production of methane from vinasse, a byproduct of ethanol production. This was used to calculate the possible additional methane production resulting from the byproducts of ethanol produced per hectare (Figure 4) as presented in Figure 7. As this production is dependent on the amount of ethanol produced, the difference in the values from crop to crop is proportional to the difference of the crop's ethanol production potential.

Considering the total possible energy contained in the produced biofuel, the theoretical energy surplus per hectare of crop was calculated in Table 3. Among the crops considered here, only orange, tobacco, rice, and cotton have a negative surplus value, meaning that they require

Table 3 - Energy demand per hectare of crop in GJ/ha, theoretical fuel yield in energy units (GJ/ha) of fuel and theoretical energy surplus per crop (GJ/ha)

	ENERGY DEMAND PER HECTARE	THEORETICAL FUEL YIELD PER HECTARE IN ENERGY UNITS	ENERGY SURPLUS PER HECTARE
COTTON	5.92	0.00	-5.92
RICE	7.80	0.00	-7.80
SUGARCANE	3.84	146.83	142.98
TOBACCO	76.30	0.00	-76.30
ORANGE	11.33	0.00	-11.33
CASSAVA	31.39	42.33	10.94
CORN	2.83	159.88	157.05
SOYBEAN	1.75	6.21	4.46
WHEAT	1.45	91.80	90.35
HEMP	4.75	183.61	178.86
CRAMBE		19.15	19.15
EUCALYPTUS (WOOD)		207.69	207.69
RAPESEED		40.00	40.00
JATROPHA		49.37	49.37

more energy than can be produced with their residues. All other considered crops are able to produce greater energy than is needed.

CONCLUSIONS

1. A review of the most recent publications on energy in the agricultural sector with a focus on Brazil was performed in this paper. The identified trends suggest that the focus of research over the last 8 years has been on sugarcane, emissions, and ethanol production. The most recent publications (i.e., published from 2020–2021) point to a continuation in this trend of research, with the markets- and indicator-based studies among the primary themes identified in the research;

2. Of the reviewed literature, tobacco has the highest energy demand, while wheat, sugarcane, and eucalyptus have the greatest ethanol production potential per hectare. Both rapeseed and jatropha were identified as having greater biodiesel production potential per hectare than soybeans; however, more studies on these seeds are needed to determine their energy requirements;

3. Of the 14 crops considered, only four had energy requirements that were greater than could be produced by their residues. Those crops were tobacco, orange, rice, and cotton. The highest energy surplus was identified for eucalyptus, industrial hemp, maize, and sugarcane, in that order;

4. Taken together, these findings seem to indicate that the Brazilian agricultural sector has the potential to generate more energy than is required by its crops for preparation, field maintenance, harvesting, and transportation. With the possible inclusion of energy crops, the agricultural sector could generate enough energy to operate with a greatly reduced amount of fossil fuels, or without them entirely. However, as illustrated in the trends identified in the literature, additional studies are needed to investigate the impacts associated with including energy crops in the Brazilian agricultural sector to further confirm this remark.

REFERENCES

ANDREA, M. C. S. *et al*. Energy Demand in Agricultural Biomass Production in Parana state, Brazil. **Agricultural Engineering International: CIGR Journal**, v. 0, n. 0, p. 42-51, 13 May 2014.

AZADI, H. *et al*. Bitter sweet: How sustainable is bio-ethanol production in Brazil? **Renewable and Sustainable Energy Reviews**, v. 16, n. 6, p. 3599-3603, 1 Aug. 2012. https://doi.org/10.1016/j.rser.2012.03.015.

BASSEGIO, D. *et al.* Oilseed crop crambe as a source of renewable energy in Brazil. **Renewable and Sustainable Energy Reviews**, v. 66, p. 311-321, 1 Dec. 2016. https://doi.org/10.1016/j.rser.2016.08.010.

BEN JEBLI, M.; BEN YOUSSEF, S. The role of renewable energy and agriculture in reducing CO 2 emissions: Evidence for North Africa countries. **Ecological Indicators**, v. 74, p. 295-301, Mar. 2017. https://doi.org/10.1016/j.ecolind.2016.11.032.

CARVALHO, N. B. *et al.* How likely is Brazil to achieve its NDC commitments in the energy sector? A review on Brazilian low-carbon energy perspectives. **Renewable and Sustainable Energy Reviews**, v. 133, p. 110343, 1 Nov. 2020. https://doi.org/10.1016/j.rser.2020.110343.

CAVALETT, O.; ORTEGA, E. Integrated environmental assessment of biodiesel production from soybean in Brazil. **Journal of Cleaner Production**, The Roles of Cleaner Production in the Sustainable Development of Modern Societies. v. 18, n. 1, p. 55-70, 1 Jan. 2010. https://doi.org/10.1016/j.jclepro.2009.09.008.

CERVI, W. R. *et al.* Bioelectricity potential from ecologically available sugarcane straw in Brazil: A spatially explicit assessment. **Biomass and Bioenergy**, v. 122, p. 391-399, 1 Mar. 2019. https://doi.org/10.1016/j.biombioe.2019.02.001.

CHAVES, L. I. *et al.* Small-scale power generation analysis: Downdraft gasifier coupled to engine generator set. **Renewable and Sustainable Energy Reviews**, v. 58, p. 491-498, 1 May 2016. https://doi.org/10.1016/j.rser.2015.12.033.

CHMIELEWSKI, A. G. Environmental Effects of Fossil fuel combustion. **INTERACTIONS: ENERGY/ENVIRONMENT**, Warsaw, no. December, 2014.

DA SILVA, C. M. S. *et al.* Biomass torrefaction for energy purposes - Definitions and an overview of challenges and opportunities in Brazil. **Renewable and Sustainable Energy Reviews**, v. 82, p. 2426-2432, 1 Feb. 2018. https://doi.org/10.1016/j.rser.2017.08.095.

DÁNIEL FRÓNA, J. S. and M. H.-R. Feeding the World : The Challenge of. n. 2017, p. 1-3, 2019.

DENG, Y. Y. *et al*. Country-level assessment of long-term global bioenergy potential. **Biomass and Bioenergy**, v. 74, p. 253-267, 1 Mar. 2015. https://doi.org/10.1016/j.biombioe.2014.12.003.

EPE. **Brazilian Energy Balance Summary Report 2017**. Rio de Janeiro: [*s. n.*], 2018.

FAO. Global Trends and Future Challenges for the Work of the Organization. **Committee on Agriculture, 23rd Session**, p. 1-89, 2012.

FAO. TABLE 2: Biofuel yields for different feedstocks and countries - Figures and Tables. 30 Oct. 2020a. Available at: https://www.greenfacts.org/en/biofuels/figtableboxes/biofuel-yields-countries.htm. Accessed on: 30 Oct. 2020.

FAO. **World Food and Agriculture - Statistical Pocketbook 2019**. Rome: [*s. n.*], 2019. https://doi.org/10.4060/ca1796en.

FAO. **World Food and Agriculture - Statistical Yearbook 2020**. Rome: [*s. n.*], 2020b. https://doi.org/10.4060/cb1329en.

FAO; EARTHSCAN. **The state of the world's land and water resources for food and agriculture (SOLAW) – Managing systems at risk**. Food and Agruculture Organization of the United Nations, Rome and Earthscan, London: [*s. n.*], 2011.

FENGLIN, J.; JIN, L.; GAOHUA, N. Study on industrial chain design and countermeasures of low-carbon facility agriculture - IEEE Conference Publication. 30 Oct. 2020. Available at: https://ieeexplore.ieee.org/document/5930927. Accessed on: 30 Oct. 2020.

FERREIRA, T. de A. *et al.* Energy balance of irrigated maize silage. **Ciência Rural**, v. 48, n. 5, 2018. DOI 10.1590/0103-8478cr20170625. Available at: http://www.scielo.br/scielo.php?script=sci_abstract&pid=S0103-84782018000500351&lng=en&nrm=iso&tlng=en. Accessed on: 30 Oct. 2020.

FORSTER-CARNEIRO, T. *et al*. Biorefinery study of availability of agriculture residues and wastes for integrated biorefineries in Brazil. **Resources, Conservation and Recycling**, v. 77, p. 78-88, 1 Aug. 2013. https://doi.org/10.1016/j.resconrec.2013.05.007.

GAETE-MORALES, C. *et al.* Life cycle environmental impacts of electricity from fossil fuels in Chile over a ten-year period. **Journal of Cleaner Production**, v. 232, p. 1499-1512, 2019. https://doi.org/10.1016/j.jclepro.2019.05.374.

GALDOS, M. *et al.* Trends in global warming and human health impacts related to Brazilian sugarcane ethanol production considering black carbon emissions. **Applied Energy**, v. 104, p. 576-582, 1 Apr. 2013. https://doi.org/10.1016/j.apenergy.2012.11.002.

GALEMBECK, F. Synergy in food, fuels and materials production from biomass. **Energy & Environmental Science**, vol. 3, no. 4, p. 393–399, 30 Mar. 2010. https://doi.org/10.1039/B921990K.

GERALDES CASTANHEIRA, É. *et al.* Environmental sustainability of biodiesel in Brazil. **Energy Policy**, v. 65, p. 680-691, 1 Feb. 2014. https://doi.org/10.1016/j.enpol.2013.09.062.

GNANSOUNOU, E.; VASKAN, P.; PACHÓN, E. R. Comparative techno-economic assessment and LCA of selected integrated sugarcane-based biorefineries. **Bioresource Technology**, v. 196, p. 364-375, 1 Nov. 2015. https://doi.org/10.1016/j.biortech.2015.07.072.

HORST, D. J.; BEHAINNE, J. J. R.; JUNIOR, P. P. de A. Lignin as alternative fuel: an estimate of the thermal energy generation potential from brazilian crops. **Environmental Progress & Sustainable Energy**, v. 36, n. 3, p. 717-722, 2017. https://doi.org/10.1002/ep.12441.

IEA. World energy balances and statistics - Data services. [*s. d.*]. **IEA**. Available at: https://www.iea.org/subscribe-to-data-services/world-energy-balances-and-statistics. Accessed on: 10 Nov. 2020.

INTERNATIONAL ENERGY AGENCY (IEA). Data and Statistics - Brazil. 2020. Available at: https://www.iea.org/data-and-statistics?country=BRAZIL&fuel=Energy supply&indicator=TPESbySource. Accessed on: 4 Nov. 2020.

KREUGER, E. *et al.* Anaerobic digestion of industrial hemp–Effect of harvest time on methane energy yield per hectare. **Biomass and Bioenergy**, v. 35, n. 2, p. 893-900, 1 Feb. 2011. https://doi.org/10.1016/j.biombioe.2010.11.005.

KUGLARZ, M. *et al.* Ethanol production from industrial hemp: Effect of combined dilute acid/steam pretreatment and economic aspects. **Bioresource Technology**, v. 163, p. 236-243, 1 Jul. 2014. https://doi.org/10.1016/j.biortech.2014.04.049.

LIU, X.; ZHANG, S.; BAE, J. The impact of renewable energy and agriculture on carbon dioxide emissions: Investigating the environmental Kuznets curve in four selected ASEAN countries. **Journal of Cleaner Production**, v. 164, p. 1239-1247, 15 Oct. 2017. https://doi.org/10.1016/j.jclepro.2017.07.086.

LOSSAU, S. *et al*. Brazil's current and future land balances: Is there residual land for bioenergy production? **Biomass and Bioenergy**, v. 81, p. 452-461, 1 Oct. 2015. https://doi.org/10.1016/j.biombioe.2015.07.024.

LYRIO DE OLIVEIRA, L. *et al*. Modelling the technical potential of bioelectricity production under land use constraints: A multi-region Brazil case study. **Renewable and Sustainable Energy Reviews**, v. 123, p. 109765, 1 May 2020. https://doi.org/10.1016/j.rser.2020.109765.

MACIEL, V. G. *et al.* Life Cycle Inventory for the agricultural stages of soybean production in the state of Rio Grande do Sul, Brazil. **Journal of Cleaner Production**, v. 93, p. 65-74, 15 Apr. 2015. https://doi.org/10.1016/j.jclepro.2015.01.016.

MANTOAM, E. J. *et al*. Embodied energy of sugarcane harvesters. **Biosystems Engineering**, v. 118, p. 156-166, 1 Feb. 2014. https://doi.org/10.1016/j.biosystemseng.2013.12.003.

MAROUN, M. R.; LA ROVERE, E. L. Ethanol and food production by family smallholdings in rural Brazil: Economic and socio-environmental analysis of micro distilleries in the State of Rio Grande do Sul. **Biomass and Bioenergy**, v. 63, p. 140-155, 1 Apr. 2014. https://doi.org/10.1016/j.biombioe.2014.02.023.

MINISTRY OF AGRICULTURE LIVESTOCK AND FOOD SUPPLY. **Brazilian Agroenergy Plan**. Brasilia: Embrapa, 2006. vol. 18, .

OECD. **OECD Economic Surveys: Brazil OVERVIEW**. Paris: [*s. n.*], 2018.

OLIVEIRA, G. de S. *et al.* CÁLCULO TEÓRICO DE UM SISTEMA DE BOMBEAMENTO FOTOVOLTAICO E SIMULAÇÃO DE APLICAÇÃO NA AGRICULTURA FAMILIAR. **IRRIGA**, v. 1, no. 2, p. 47-52, 10 Oct. 2018. https://doi.org/10.15809/irriga.2018v1n2p47-52.

PIGHINELLI, A. L. M. T.; SCHAFFER, M. A.; BOATENG, A. A. Utilization of eucalyptus for electricity production in Brazil via fast pyrolysis: A techno-economic analysis. **Renewable Energy**, v. 119, p. 590-597, 1 Apr. 2018. https://doi.org/10.1016/j.renene.2017.12.036.

POPP, J. *et al*. The effect of bioenergy expansion: Food, energy, and environment. **Renewable and Sustainable Energy Reviews**, v. 32, p. 559-578, 2014. https://doi.org/10.1016/j.rser.2014.01.056.

PORTE, A. F. *et al*. Sunflower biodiesel production and application in family farms in Brazil. **Fuel**, v. 89, n. 12, p. 3718-3724, 1 Dec. 2010. https://doi.org/10.1016/j.fuel.2010.07.025.

PORTUGAL-PEREIRA, J. *et al.* Agricultural and agro-industrial residues-to-energy: Techno-economic and environmental assessment in Brazil. **Biomass and Bioenergy**, v. 81, p. 521-533, 1 Oct. 2015. https://doi.org/10.1016/j.biombioe.2015.08.010.

PRADE, T.; SVENSSON, S.-E.; MATTSSON, J. E. Energy balances for biogas and solid biofuel production from industrial hemp. **Biomass and Bioenergy**, v. 40, p. 36-52, 1 May 2012. https://doi.org/10.1016/j.biombioe.2012.01.045.

RAMAN, J. K.; GNANSOUNOU, E. Ethanol and lignin production from Brazilian empty fruit bunch biomass. **Bioresource Technology**, v. 172, p. 241-248, 1 Nov. 2014. https://doi.org/10.1016/j.biortech.2014.09.043.

RAMOS, R. A.; BALBUENO, R. A.; PINHEIRO, E. S. **Paisagem, uso e cobertura da terrafile:///C:/Users/bj_ed/OneDrive - th-koeln.de/Waste to energy Brazil/Sources/Summary Report 2018.pdf**. Brasilia: [*s. n.*], 2017.

REZENDE, M. L.; RICHARDSON, J. W. Risk analysis of using sweet sorghum for ethanol production in southeastern Brazil. **Biomass and Bioenergy**, v. 97, p. 100-107, 1 Feb. 2017. https://doi.org/10.1016/j.biombioe.2016.12.016.

RIBEIRO, A. P.; RODE, M. Residual biomass energy potential: perspectives in a peripheral region in Brazil. **Clean Technologies and Environmental Policy**, v. 21, n. 4, p. 733-744, 1 May 2019. https://doi.org/10.1007/s10098-019-01675-3.

SCHEIDL, H. A. *et al*. Environmental impacts of mechanization in Brazil's sugar and ethanol industry: The cutting, loading, and transportation process case. **Environmental Progress & Sustainable Energy**, v. 34, n. 6, p. 1748-1755, 2015. https://doi.org/10.1002/ep.12159.

SCOPUS. Scopus - Document search. [*s. d.*]. Available at: https://www.scopus.com/search/form.uri?display=basic. Accessed on: 30 Oct. 2020.

SILVA NETO, J. V.; GALLO, W. L. R. Potential impacts of vinasse biogas replacing fossil oil for power generation, natural gas, and increasing sugarcane energy in Brazil. **Renewable and Sustainable Energy Reviews**, v. 135, p. 110281, 1 Jan. 2021. https://doi.org/10.1016/j.rser.2020.110281.

SMEETS, E. M. W.; FAAIJ, A. P. C. The impact of sustainability criteria on the costs and potentials of bioenergy production - Applied for case studies in Brazil and Ukraine. **Biomass and Bioenergy**, v. 34, n. 3, p. 319-333, 1 Mar. 2010. https://doi.org/10.1016/j.biombioe.2009.11.003.

SOCCOL, C. R.*et al*. Bioethanol from lignocelluloses: Status and perspectives in Brazil. **Bioresource Technology**, Special Issue on Lignocellulosic Bioethanol: Current Status and Perspectives.

v. 101, n. 13, p. 4820-4825, 1 Jul. 2010. https://doi.org/10.1016/j.biortech.2009.11.067.

TAKAHASHI, F.; ORTEGA, E. Assessing the sustainability of Brazilian oleaginous crops - possible raw material to produce biodiesel. **Energy Policy**, Greater China Energy: Special Section with regular papers. v. 38, n. 5, p. 2446-2454, 1 May 2010. https://doi.org/10.1016/j.enpol.2009.12.038.

TEIXEIRA, P. **TEXTO SUBSTITIVO DO PROJETO DE LEI DE REGULAMENTAÇÃO DO USO DE MEDICAMENTOS FORMULADOS COM CANNABIS**. 19 Aug. 2020. **Paulo Teixeira | Deputado Federal | PT-SP**. Available at: http://pauloteixeira13.com.br/projetos-de-lei/texto-substitivo-do-projeto-de-lei-de-regulamentacao-do-uso-de-medicamentos-formulados-com-cannabis/. Accessed on: 30 Oct. 2020.

THE WORLD BANK. The World Bank in Brazil. 2020. Available at: https://www.worldbank.org/en/country/brazil/overview#:~:text=The World Bank's support of,of the country's natural resources. Accessed on: 4 Nov. 2020.

TIEPPO, R. C. *et al*. Modeling cost and energy demand in agricultural machinery fleets for soybean and maize cultivated using a no-tillage system. **Computers and Electronics in Agriculture**, v. 156, p. 282-292, 1 Jan. 2019. https://doi.org/10.1016/j.compag.2018.11.032.

TILMAN, D. *et al*. Global food demand and the sustainable intensification of agriculture. **Proceedings of the National Academy of Sciences of the United States of America**, v. 108, n. 50, p. 20260-20264, 2011. https://doi.org/10.1073/pnas.1116437108.

VOGT, H. H.; ALBIERO, D.; SCHMUELLING, B. Electric tractor propelled by renewable energy for small-scale family farming. *In*: 2018 THIRTEENTH INTERNATIONAL CONFERENCE ON ECOLOGICAL VEHICLES AND RENEWABLE ENERGIES (EVER), Apr. 2018. **2018 Thirteenth International Conference on Ecological Vehicles and Renewable Energies (EVER)** [...]. [*S. l.*: *s. n.*], Apr. 2018. p. 1-4. https://doi.org/10.1109/EVER.2018.8362344.

WELFLE, A. Balancing growing global bioenergy resource demands - Brazil's biomass potential and the availability of resource for trade. **Biomass and Bioenergy**, v. 105, n. 2017, p. 83-95, 2017. https://doi.org/10.1016/j.biombioe.2017.06.011.

WORLD BIOENERGY ASSOCIATION. **Global Bioenergy Statistics 2019 World Bioenergy Association**. Stockholm: [*s. n.*], 2019.

ZAPALOWSKA, A.; BASHUTSKA, U. The use of agricultural waste for the renewable energy production. **Наукові Праці Лісівничої Академії Наук України**, n. 18, p. 138-144, 2019. https://doi.org/10.15421/411914.