Technical Note

AGRICULTURE AND LIVESTOCK, ENERGY AND THE FOREST-SPARING EFFECT: AN INTERNATIONAL COMPARISON

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1 INTRODUCTION[1]

This technical report aims to study agribusiness production and analyzes some sustainability indicators. We compare the Brazilian economy with the central agro-exporter countries: Argentina, Canada, China, France, Germany, India, and the United States. It is a complementary analysis of the results highlighted by Vieira Filho (2022a). Furthermore, the economic research seeks to advance in an international comparison of Brazil with those countries.

Brazil has been committed to environmental issues and has become a player on several associated fronts since the 1990s. In 1992, it was worth highlighting that Brazil held the United Nations Conference on the Environment (Rio-92). At the beginning of the 2000s, the Brazilian released satellite images (a pioneer action)[2] provided public efforts to reduce deforestation in the Amazon region. The consequence has resulted in a pronounced reduction in deforestation rates and a decrease in greenhouse gas (GHG) emissions nationwide by around 80.9 percent since 2005 (Brasil, 2021b). In 2010, the Brazilian government created the Low Carbon Agriculture Program[3] to support sustainable production processes using rural credit channels. In 2012, Congress voted on the Forest Code,[4] which included demands for environmental preservation. These reasons lead us to evaluate the period that starts in 1990 and finishes around 2022 whenever economic data is available.

The world's significant economies know that agricultural and livestock production is essential for economic development, and this is why periods of instability in global food supply chains raise many concerns. The centrality of the farming sector, in any context, is linked to the production of food, energy, and productive and environmental sustainability. Brazil was an example for the world as a country able to create an induced institutional building in tropical agriculture (Alves, 2010; Vieira Filho, 2022b). Since the 1970s, the increase in agricultural productivity has allowed the expansion of food supply at a higher level than the growth of demand, which has reduced the price of agricultural goods (Alves, Souza and Brandão, 2010).

Recently, ag-inflation has raised food security concerns. The rise of world inflation is related to combinations of different adverse shocks. There are exogenous variables such as the reopening of post-pandemic economies, high oil prices, the Russia and Ukraine conflict, climate problems (such as droughts and frosts last year), and shortages of imported inputs from China. Concerning the Brazilian economy, there are also internal factors such as political uncertainties from electoral time and a relative increase in public spending amidst tribute incentives. Therefore, there is a world economic environment for wide negative shocks.

Wages are going up because of the ending of global labor arbitrage with China at the center. There are disruptions to the value chain's production with shortages of imported inputs worldwide. Food and energy prices are going high. Finally, public spending has increased over the covid-19 pandemic crisis. In Brazil, public expenditure has relatively upgraded to support vulnerable people in 2020, yet dropped before the reopening of the economy last year. At the same time, on the opposite side of the economic policies around the world, Brazilian Central Bank supplied financial credit for the productive sector (industry and agriculture) in 2020. Then policymakers have promoted an upturn in interest rates to control inflation since 2021. Unfortunately, Brazil was the only country to combat inflation on the monetary and fiscal front. In addition, maintaining agricultural productivity growth at high levels has avoided domestic and foreign shortages of food and contributed to better controlling inflation in the medium and long terms.

1. We thank Zenaide Rodrigues Ferreira from the Agricultural Study Center at the Institute for Applied Economic Research (Ipea) for organizing the entire presented database; and José Garcia Gasques for the comments and information data discussed in the session on total factor productivity (TFP).

2. See Silva and Vieira Filho (2020).

3. Also called ABC Program, it is one of the sectoral plans prepared under article 3 of Decree No. 7,390 from 2010 (available at: <https://bit.ly/3xlv9on>). The ABC plan was valid until 2020. In 2021, the ABC+ Plan was an update for the period 2020-2030 (Brasil, 2021a). The target was to expand the area of sustainable technology adoption by 72.7 million hectares, increase treated animal waste by 208.4 million m^3, and slaughter 5 million cattle in intensive production. As a result, the mitigation capacity is equivalent to 1,110.34 Mg CO2eq (millions of grams of carbon dioxide equivalent). See Silva and Vieira Filho (2020) and Telles et al. (2021) for an evaluation of the first-decade program.

4. The Law No. 12,651 from 2012 established general rules on the protection of native vegetation, including permanent preservation areas, legal reserves (or private areas preserved on a farm), and restricted use land (available at: <https://bit.ly/3aymMx2>). For a study that compares forest protection and land use legislation of some of the world's top ten exporters of agricultural products, including Argentina, Brazil, Canada, China, France, Germany, and the United States, see Chiavari and Mendes (2017).

Before any evaluation, it is necessary to understand the concept of sustainability. There is no sustainable production if the center of our hypothesis is not the human being. Therefore, we believe that there is a socioeconomic problem behind the environmental assumption. Farmers have no interest in destroying the environment. On the contrary, their actions are central to the productive and inclusive development model. Therefore, the concept of *sustainable development is defined as using inputs (including scarce natural resources) to meet human needs and provide outputs in the present without compromising future generations' development and economic production.*[5]

According to the Agricultural Census 2017 by the Brazilian Institute of Geography and Statistics (IBGE), 9 percent of the wealthiest agricultural farms accounted for 85 percent of production value; while 91 percent of the poorest rural farms were responsible for only 15 percent of production value (Vieira Filho and Gasques, 2020). Environment preservation and sustainable development do not work without human life. *Our farmers produce food, generate energy, and fundamentally preserve the environment.*

This study is divided into four sections to meet these productive sustainability problems and challenges. The first is this brief introduction. The second one makes an international comparison of agricultural and livestock production. The third section analyses production per unit of GHG emission and the energy matrix of the studied countries. Finally, there are suggestions highlighted for public policy implementation.

2 INTERNATIONAL ANALYSIS AT THE PRODUCTION LEVEL

2.1 Global production concern: ag-inflation and food security

In recent years and mainly after the pandemic crisis, food prices have increased while a spike marked world hunger (table 1). The food price index has raised more than the consumer prices. From 2015 to 2019, food prices have accounted for a fewer average annual rate of growth than the consumer prices index. After the pandemic, food price behavior has inverted, and it tends to be higher than before. According to official statistics from FAO,[6] the number of people undernourished achieved the lowest bottom line around 2015. From 2015 to 2021, these vulnerable people have expanded, and more than half currently live in Asia (418 million), more than a third in Africa (282 million), and a smaller proportion in Latin America and the Caribbean (68 million). While the pandemic's impact has yet to be mapped, United Nations has projected estimates that undernourished people were roughly a tenth of the global population (up to 811 million people) in the past few years.

Regarding the Brazilian fiscal and monetary policies, at the beginning of the pandemic year 2020, total public spending increased by 15.3 percent while gross domestic product varied by a negative 11.5 percent. However, as seen in figure 1, Brazilian Central Bank spread into the market a cheap financial credit to avoid business bankrupts and job losses. Since 2021, as expectations of inflation rates have grown, the monetary policy has changed while the fiscal policy has generally reduced public spending. First, income transfer assistance and more healthcare expenditures have covered vulnerable people during the pandemic. Then social spending was reduced, and the interest rate grew in 2021. This countercyclical economic policy has contributed to saving jobs and turned the quarterly Brazilian GDP growth trajectory into "V". Brazil was the only country to combat inflation on the monetary and fiscal fronts. It is essential to mention that agricultural production of cereals presented the highest harvest in 2020, with 257 million tons during this difficult time. Even in 2021, the cereal harvest was the second-highest in the Brazilian production time series. Brazil has a lot to help the world reduce hunger and expand the food supply. This contribution will undoubtedly come through productivity gains.

5. For a more detailed discussion of the conceptual approach, see CMMAD (1991), and Alvarez and Mota (2010).
6. Available at: <https://bit.ly/3xAqNKM>.

TABLE 1

Brazilian and world economic indicators (production, prices, public expenditures, and people undernourished) in recent years

Region	Economic indicator	2015	2019	2020	2021	Δ percent (2019-2020)	Δ percent (2020-2021)	Average annual rate of growth – percent (2015-2021)
Brazil	Cereal's total production (1 million tons)	208.6	246.8	257.0	255.5	4.1	-0.6	3.4
	Food prices index (2015 = 100)	100.0	120.0	130.9	145.4	9.1	11.0	6.4
	Consumer prices index (2015 = 100)	100.0	121.0	124.8	133.3	3.2	6.8	4.9
	Income transfer (R$ 1 billion)[1]	127.0	136.6	524.9	161.1	284.3	-69.3	4.0
	Social security (R$ 1 billion)[1]	969.6	1044.6	972.8	804.5	-6.9	-17.3	-3.1
	Health (R$ 1 billion)[1]	166.9	163.9	192.4	161.4	17.4	-16.1	-0.6
	Rest of spending (R$ 1 billion)[1]	2,787.5	2,586.7	2,845.1	2,764.2	10.0	-2.8	-0.1
	Total public spending (R$ 1 billion)[1]	4,051.0	3,931.8	4,535.2	3,891.3	15.3	-14.2	-0.7
	Gross domestic product (R$ 1 billion)[1]	10,381.7	10,079.2	8,915.8	8,700.0	-11.5	-2.4	-2.9
World	Food prices index (2015 = 100)	100.1	111.6	118.7	125.2	6.3	5.5	3.8
	Consumer prices index (2015 = 100)	100.0	113.0	116.9	123.1	3.5	5.3	3.5
	People undernourished (1 million)	615.1	650.3	768.0	768.0[2]	18.1	-	3.8

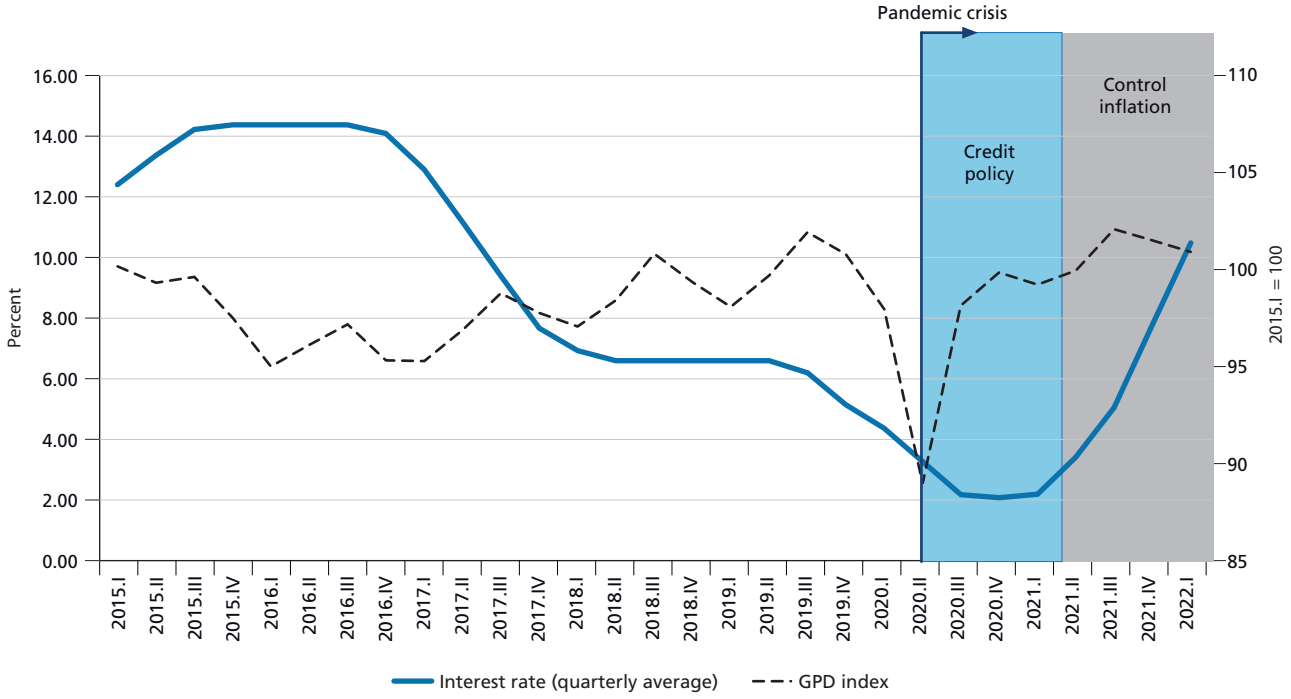
Sources: Conab (available at: <https://bit.ly/3GYKi2q>); Tesouro Nacional (available at: <https://bit.ly/3xnjN3f>); and FAO (available at: <https://bit.ly/3xAqNKM>).

Notes: [1] Monetary values deflated at 2021 prices by the IGP-DI.

[2] Number of 2020.

FIGURE 1

Interest rate and GDP index (quarterly) in Brazil since 2015



Sources: Central Bank of Brazil (available at: <https://bit.ly/3aK8hpZ>); and IBGE's quaterly national accounts (available at: <https://bit.ly/3MxoqMK>).

2.2 TFP[1]

Table 2 presents the countries with relevant insertion in the international commodity market. From 1990 to 2019, Brazil, China, and India have the best comparative performances in productivity. Over the last three decades, Brazil achieved the highest annual growth rate of TFP (3.10 percent). In general, these countries were also the ones that led the growth of the world agricultural TFP. The information released by the USDA showed that Brazil began to teach the rank of TFP in the 2000s.[2] This outcome was consistent with the studies published in Brazil since productivity began to grow at rates above 4 percent per year in that period (Gasques et al., 2012; 2020; Alcantara, Vieira Filho and Gasques, 2021).

TABLE 2
Agricultural TFP index by selected countries (1990-2019)

Country	TFP index (2015 = 100)				Average annual rate of growth (percent)			
	1990	2000	2010	2019	1st decade (1990-2000)	2nd decade (2000-2010)	3rd decade (2010-2019)	Total (1990-2019)
Argentina	79	93	93	98	1.72	-0.02	0.54	0.75
Brazil	44	62	87	107	3.48	3.43	2.33	3.10
Canada	70	80	95	110	1.36	1.75	1.56	1.56
China	51	75	91	105	3.93	1.95	1.66	2.54
France	82	88	95	102	0.79	0.70	0.83	0.77
Germany	83	88	97	105	0.68	0.94	0.85	0.82
India	67	72	87	115	0.68	1.97	3.16	1.89
United States	82	95	104	100	1.47	0.90	-0.44	0.68
World	68	79	92	105	1.53	1.65	1.41	1.53

Source: USDA. Available at: <https://bit.ly/3NrxyDE>.

2.3 Agriculture and livestock production & the forest-sparing effect

Table 3 shows agricultural production, harvested area, and productive yield (tons per hectare) of the selected countries. Three decades were analyzed. Regarding production, Argentina and Brazil led the growth rate from 1990 to 2019, with 3.48 and 3.43 percent, respectively. In particular, Brazil had the highest growth rate in the second evaluated decade. France experienced declines for the entire period. In addition, France had the worst performance in the third decade. Germany experimented with the lowest growth rate in the second decade as well. According to the harvested area statistics, Argentina was the country with the highest growth in the total period. Brazil decreased its harvested area in the first decade but increased it in the second one achieving the highest growth rate (1.30 percent), and then stabilized in the last decade at around 0.95 percent. Overall, Germany, the United States, Canada, and France have reduced their respective harvested areas. Finally, in terms of agricultural yield, Brazil led the entire period with a rate of 2.74 percent. Additionally, Brazil obtained one of the highest rates during the first and second decades. The worst observed agricultural yields were in France and Germany. The higher the yield performance is, the greater the country´s capacity to produce with technical efficiency. Brazil stood out in this regard.

1. TFP growth can be understood as a rise in output that an input increase cannot explain. Usually, it measures the residual factor, given by the difference between output and input growth rates. It is an estimation of productivity gains. The technical report organized by the United States Department of Agriculture (USDA) estimates TFP through the Tornqvist index (available at: <https://bit.ly/3NrxyDE>). More details on the concept involved in calculating TFP can be found in Jorgenson (1995) and Alves (2004).

2. Available at: <https://bit.ly/3NrxyDE>.

TABLE 3
Agricultural production, area harvested, and yield by selected countries (1990-2020)

Variable	Country	Year				Average annual rate of growth (percent)			
		1990	2000	2010	2020	1st decade (1990-2000)	2nd decade (2000-2010)	3rd decade (2010-2019)	Total (1990-2019)
Production (1 million tons)	Argentina	62.5	97.9	128.8	174.4	4.58	2.78	3.08	3.48
	Brazil	399.5	503.2	965.5	1099.6	2.33	6.73	1.31	3.43
	Canada	69.9	74.3	77.9	108.7	0.62	0.47	3.40	1.48
	China	819.6	1168.2	1526.0	1827.5	3.61	2.71	1.82	2.71
	France	119.3	128.2	126.5	111.2	0.73	-0.13	-1.29	-0.23
	Germany	92.5	98.6	89.1	93.7	0.64	-1.01	0.51	0.04
	India	551.4	721.5	845.8	1087.3	2.72	1.60	2.54	2.29
	United States	507.1	607.2	649.0	707.5	1.82	0.67	0.87	1.12
Area harvested (1 million hectares)	Argentina	9.9	12.4	9.7	18.7	2.29	-2.43	6.81	2.15
	Brazil	34.0	33.2	37.8	41.6	-0.23	1.30	0.95	0.67
	Canada	22.2	21.2	16.4	20.0	-0.47	-2.50	1.97	-0.35
	China	122.7	130.2	141.1	151.1	0.59	0.80	0.69	0.70
	France	12.0	11.5	11.5	11.1	-0.47	0.00	-0.35	-0.27
	Germany	8.7	8.3	7.6	7.2	-0.45	-0.92	-0.55	-0.64
	India	138.8	138.2	148.6	161.0	-0.04	0.73	0.81	0.50
	United States	71.4	64.5	63.3	59.1	-1.00	-0.19	-0.69	-0.63
Yield (tons/ hectare)	Argentina	6.3	7.9	13.3	9.3	2.24	5.35	-3.50	1.30
	Brazil	11.7	15.1	25.5	26.4	2.57	5.36	0.35	2.74
	Canada	3.2	3.5	4.7	5.4	1.09	3.04	1.40	1.84
	China	6.7	9.0	10.8	12.1	3.00	1.89	1.12	2.00
	France	9.9	11.2	11.0	10.0	1.21	-0.13	-0.94	0.04
	Germany	10.6	11.8	11.7	13.0	1.10	-0.09	1.06	0.69
	India	4.0	5.2	5.7	6.8	2.77	0.87	1.72	1.78
	United States	7.1	9.4	10.2	12.0	2.85	0.86	1.57	1.76

Source: FAO. Available at: <https://bit.ly/3xAqNKM>.

Table 4 focuses on livestock production and compares the main economic statistics of these countries. Chinese animal stock from 1990 to 2019 has decreased while the pasture land has stabilized since 2000. The carcass weight showed a negative performance, and the reduced production yield was significantly due to the early slaughter of the animals in China. Therefore, the Chinese livestock production was very feeble compared to other countries. Brazil presented the best productive outcome (yield and carcass weight). The carcass weight of cattle rose over the period, increasing production yield. Simultaneously, there was an increase in Brazilian output. At the same time, pasture land decreased, signifying an increase in the stocking rate. In 2020, three-quarters of animal stocks were concentrated in Brazil, India, and the United States, in that order. However, beef consumption in India is not widespread for cultural and religious reasons. Livestock production in France and Germany has been falling over time, besides losing competitiveness. Productive intensification in these two countries is also decreasing.

TABLE 4

Livestock production, animal stock, pastures, carcass weight, stocking rate, and yield by selected countries (1990-2020)

Variable	Country	Year				Average annual rate of growth (percent)			
		1990	2000	2010	2020	1st decade (1990-2000)	2nd decade (2000-2010)	3rd decade (2010-2019)	Total (1990-2019)
Production (1 million kg)	Argentina	11,837.3	10,669.4	10,832.6	12,335.4	-1.03	0.15	1.31	0.14
	Brazil	26,905.0	35,877.7	48,466.9	73,713.0	2.92	3.05	4.28	3.42
	Canada	3,010.4	4,348.5	4,196.3	4,399.0	3.75	-0.36	0.47	1.27
	China	11,857.9	14,919.8	10,041.4	9,047.1	2.32	-3.88	-1.04	-0.90
	France	6,129.4	5,930.5	5,796.2	5,689.0	-0.33	-0.23	-0.19	-0.25
	Germany	5,826.7	4,457.5	4,058.0	3,757.9	-2.64	-0.93	-0.77	-1.45
	India	20,371.5	19,768.2	20,001.1	20,031.7	-0.30	0.12	0.02	-0.06
	United States	28,428.6	31,394.2	31,517.2	34,741.0	1.00	0.04	0.98	0.67
Animal stock (1 million's head)	Argentina	52.8	48.7	48.9	54.5	-0.82	0.06	1.07	0.10
	Brazil	147.1	169.9	209.5	218.2	1.45	2.12	0.40	1.32
	Canada	11.2	13.2	12.7	11.3	1.64	-0.41	-1.17	0.01
	China	77.9	104.6	68.9	61.1	2.99	-4.09	-1.19	-0.81
	France	21.4	21.3	19.6	17.8	-0.06	-0.83	-0.94	-0.61
	Germany	20.3	14.7	12.8	11.3	-3.20	-1.34	-1.24	-1.93
	India	202.5	191.9	194.2	194.5	-0.53	0.12	0.02	-0.13
	United States	95.8	98.2	94.1	93.8	0.25	-0.43	-0.03	-0.07
Land under permanent meadows and pastures (1 million hectares)	Argentina	100.0	99.9	87.3	74.7[1]	-0.01	-1.34	-1.55	-0.97
	Brazil	178.4	173.5	170.2	173.4[1]	-0.28	-0.19	0.19	-0.10
	Canada	19.9	20.1	20.4	19.3[1]	0.11	0.13	-0.54	-0.10
	China	374.4	392.8	392.8	392.8[1]	0.48	0.00	0.00	0.16
	France	11.6	10.3	9.6	9.5[1]	-1.17	-0.70	-0.07	-0.65
	Germany	5.6	5.0	4.7	4.8[1]	-1.06	-0.81	0.20	-0.56
	India	11.3	10.8	10.3	10.3[1]	-0.41	-0.48	-0.08	-0.32
	United States	239.2	236.3	246.6	245.4[1]	-0.12	0.43	-0.05	0.09
Carcass weight (kg/ head)	Argentina	224.0	219.2	221.3	226.5	-0.22	0.10	0.23	0.04
	Brazil	182.9	211.2	231.3	337.9	1.45	0.91	3.86	2.07
	Canada	268.3	329.4	331.2	390.5	2.07	0.05	1.66	1.26
	China	152.2[2]	142.7	145.8	148.0	-0.64	0.22	0.15	-0.09
	France	286.5	279.0	296.4	319.8	-0.26	0.61	0.76	0.37
	Germany	287.2	304.1	316.8	332.5	0.57	0.41	0.48	0.49
	India	100.6	103.0	103.0	103.0	0.24	0.00	0.00	0.08
	United States	296.7	319.7	335.0	370.4	0.75	0.47	1.01	0.74
Stoking rate (head/ hectare)	Argentina	0.53	0.49	0.56	0.73	-0.81	1.42	2.66	1.08
	Brazil	0.82	0.98	1.23	1.26	1.74	2.32	0.22	1.42
	Canada	0.56	0.66	0.62	0.58	1.53	-0.54	-0.63	0.11
	China	0.21	0.27	0.18	0.16	2.49	-4.09	-1.19	-0.96
	France	1.84	2.06	2.03	1.86	1.12	-0.13	-0.87	0.03
	Germany	3.61	2.90	2.75	2.38	-2.16	-0.54	-1.45	-1.38
	India	17.91	17.70	18.78	18.95	-0.12	0.60	0.09	0.19
	United States	0.40	0.42	0.38	0.38	0.37	-0.85	0.02	-0.16

(Continues)

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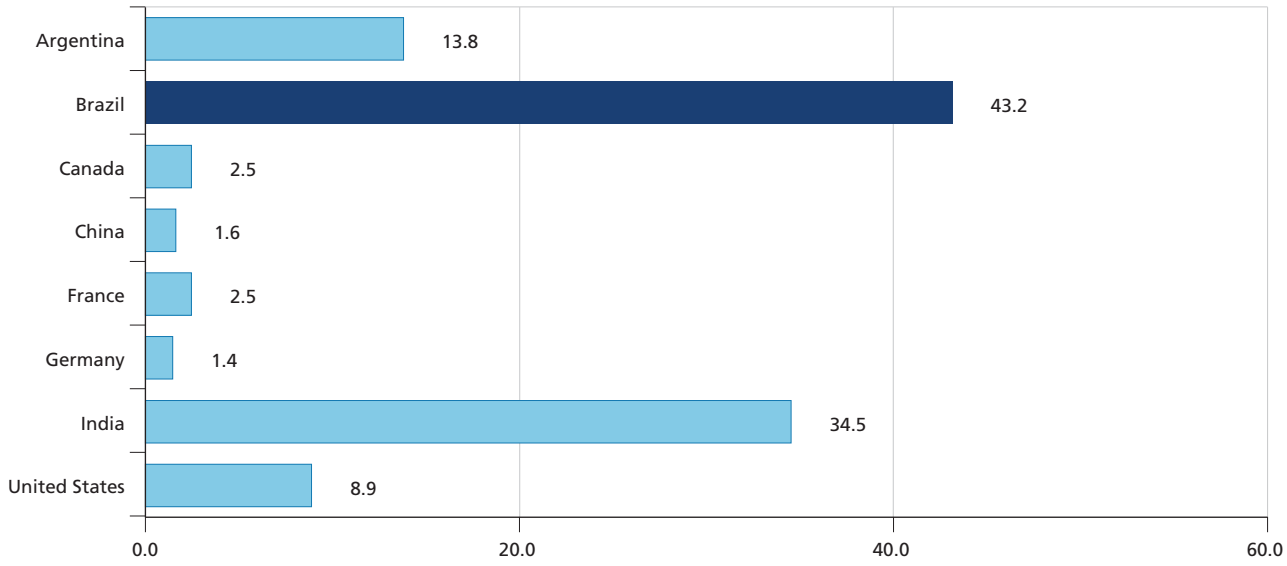
Variable	Country	Year				Average annual rate of growth (percent)			
		1990	2000	2010	2020	1st decade (1990-2000)	2nd decade (2000-2010)	3rd decade (2010-2019)	Total (1990-2019)
Yield (kg/hectare)	Argentina	118.4	106.8	124.1	165.2	-1.02	1.51	2.90	1.12
	Brazil	150.8	206.8	284.8	425.2	3.21	3.25	4.09	3.52
	Canada	151.1	215.8	205.5	227.4	3.63	-0.49	1.02	1.37
	China	31.7	38.0	25.6	23.0	1.83	-3.88	-1.04	-1.06
	France	528.4	575.1	602.9	596.0	0.85	0.47	-0.11	0.40
	Germany	1,037.1	883.0	871.8	791.0	-1.60	-0.13	-0.97	-0.90
	India	1,802.1	1,822.8	1,934.5	1,952.2	0.11	0.60	0.09	0.27
	United States	118.9	132.8	127.8	141.6	1.12	-0.38	1.03	0.58

Source: FAO. Available at: <https://bit.ly/3xAqNKM>.
Notes: [1] 2019.
[2] 1991.

By analyzing agriculture and livestock productive development, this study measures the forest-sparing effect,[3] an index of the impact of technical change on crop or livestock production. To calculate the forest-sparing impact, it is crucial to answering the question: what is the extent of the land size needed to produce the current quantity of food or meat, given the past yield patterns? If a yield increase over time is observed, this answer indicates the forest area saved to produce the same quantity of product afterward. Thus, the indicator can measure the extent of land size and scarce resources spared due to technological changes.

As shown in figure 2, Brazil and India led the ranking of the forest-sparing effect. The Brazilian upshot is due to productivity gains in general, both in agriculture and livestock. On the other hand, the Indian case was exclusively associated with agricultural production since its livestock response was feeble. Germany, China, France, and Canada showed the lowest results, not contributing to productive and environmental sustainability. Figure 3 presents the Brazilian contribution share of the forest-sparing effect by the national territory and its temporal dimension.

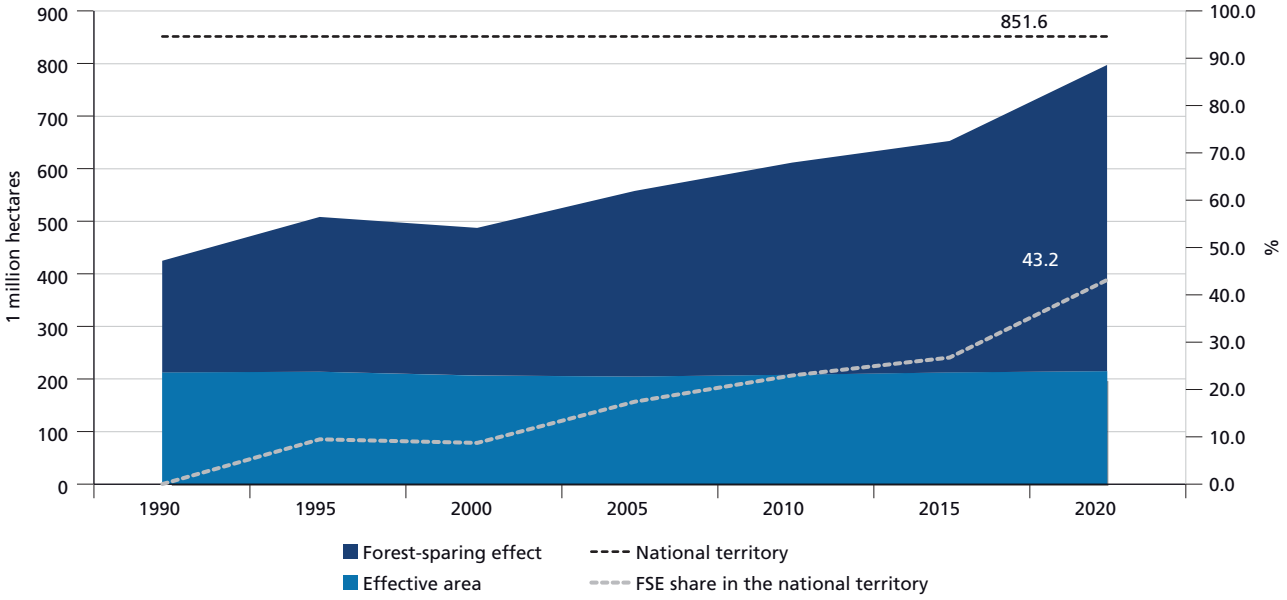
FIGURE 2
Share of forest-sparing effect in the national territory by selected countries: agriculture and livestock contribution (2020)
(In percent)



Source: FAO. Available at: <https://bit.ly/3xAqNKM>.
Elaborated by the author.

3. This concept is similar to the land-saving approach studied by Martha Júnior, Alves, and Contini (2012). To take a deep look at the Brazilian livestock expansion, see Vieira Filho (2017).

FIGURE 3
Brazilian forest-sparing effect (agriculture and livestock) in the national territory (1990-2020)



Source: FAO. Available at: <https://bit.ly/3xAqNKM>.
Elaborated by the author.

2.4 Land use change

According to data in table 5, Brazilian cropland, compared to other countries, exhibited one of the smallest percentages (7.5 percent) of the total area occupied, being below India (51.5 percent), France (34.7 percent), Germany (33.3 percent), the United States (16.3 percent), China (14.1 percent) and Argentina (12.1 percent). When comparing the area destined for agriculture and livestock (cropland plus pastures), Brazil had one of the lowest percentages (27.8 percent). Again it was in a more favorable position compared to other countries, such as China (55.1 percent), India (54.6 percent), France (52.1 percent), Germany (46.6 percent), United States (41.3 percent), and Argentina (39 percent). Furthermore, concerning areas of native and planted forests, Brazil showed the highest share of preserved land (58.5 percent), while othaer countries presented lower percentages, generally below 35 percent. In the last decade, reducing native and planted forests represented deforestation of only 2.9 million hectares[4] or roughly 0.3 percent of the national territory. Brazil only occupies 1.3 percent of its land regarding planted forests, while Germany has the highest share, reaching 16 percent of this indicator. On the one hand, Brazil had one of the highest growth rates for planted forests, especially in the last two decades. On the other hand, Germany had the lowest growth rate from 1990 to 2019.

TABLE 5
Land use by selected countries (1990-2019)

Land use	Country	Year (1 million hectares)				Share in the national territory – percent (2019)	Average annual rate of growth (percent)			
		1990	2000	2010	2019		1st decade (1990-2000)	2nd decade (2000-2010)	3rd decade (2010-2019)	**Total (1990-2019)**
Cropland	Argentina	27.6	28.6	39.0	33.7	12.1	0.37	3.14	-1.61	**0.69**
	Brazil	56.5	54.9	61.7	63.5	7.5	-0.28	1.17	0.33	**0.41**
	Canada	41.5	41.1	37.9	38.8	3.9	-0.08	-0.83	0.28	**-0.23**
	China	132.2	130.9	136.1	135.7	14.1	-0.10	0.39	-0.03	**0.09**
	France	19.0	19.5	19.3	19.1	34.7	0.26	-0.09	-0.14	**0.01**
	Germany	12.4	12.0	12.0	11.9	33.3	-0.32	0.02	-0.12	**-0.14**
	India	170.1	170.1	169.2	169.3	51.5	0.00	-0.05	0.01	**-0.02**
	United States	187.8	178.1	160.4	160.4	16.3	-0.53	-1.04	0.00	**-0.54**

(Continues)

4. The net deforestation is the difference between native forests in 2010 and the sum of native and planted forests in 2019 [551.6-(497.8+10.9)].

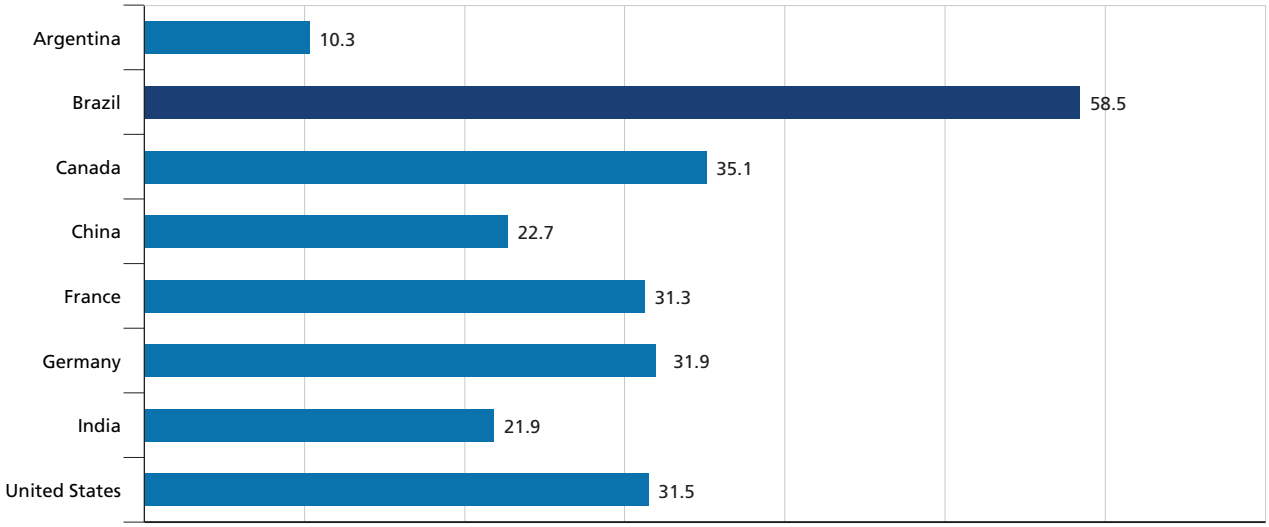
(Continued)

Land use	Country	Year (1 million hectares)				Share in the national territory – percent (2019)	Average annual rate of growth (percent)			
		1990	2000	2010	2019		1st decade (1990-2000)	2nd decade (2000-2010)	3rd decade (2010-2019)	**Total (1990-2019)**
Pastures	Argentina	100.0	99.9	87.3	74.7	26.9	-0.01	-1.34	-1.72	**-1.00**
	Brazil	178.4	173.5	170.2	173.4	20.4	-0.28	-0.19	0.21	**-0.10**
	Canada	19.9	20.1	20.4	19.3	2.0	0.11	0.13	-0.60	**-0.10**
	China	374.4	392.8	392.8	392.8	40.9	0.48	0.00	0.00	**0.17**
	France	11.6	10.3	9.6	9.5	17.4	-1.17	-0.70	-0.08	**-0.67**
	Germany	5.6	5.0	4.7	4.8	13.3	-1.06	-0.81	0.23	**-0.58**
	India	11.3	10.8	10.3	10.3	3.1	-0.41	-0.48	-0.08	**-0.33**
	United States	239.2	236.3	246.6	245.4	25.0	-0.12	0.43	-0.05	**0.09**
Native forests	Argentina	35.2	33.4	30.2	28.7	10.3	-0.53	-0.99	-0.58	**-0.70**
	Brazil	588.9	551.1	511.6	497.8	58.5	-0.66	-0.74	-0.30	**-0.58**
	Canada	348.3	347.8	347.3	347.0	35.1	-0.01	-0.01	-0.01	**-0.01**
	China	157.1	177.0	200.6	218.1	22.7	1.20	1.26	0.93	**1.14**
	France	14.4	15.3	16.4	17.2	31.3	0.58	0.72	0.50	**0.60**
	Germany	11.3	11.4	11.4	11.4	31.9	0.05	0.05	0.01	**0.04**
	India	63.9	67.6	69.5	71.9	21.9	0.56	0.28	0.38	**0.41**
	United States	302.5	303.5	308.7	309.8	31.5	0.04	0.17	0.04	**0.08**
Planted forests	Argentina	0.8	1.1	1.2	1.4	0.5	3.46	0.99	1.89	**2.11**
	Brazil	3.6	3.7	7.3	10.9	1.3	0.26	7.21	4.47	**3.92**
	Canada	4.6	9.4	14.0	17.7	1.8	7.35	4.09	2.65	**4.75**
	China	44.2	54.8	73.3	83.6	8.7	2.19	2.95	1.47	**2.23**
	France	1.5	1.6	2.1	2.4	4.4	0.37	2.71	1.64	**1.57**
	Germany	5.7	5.7	5.7	5.7	16.0	0.05	0.05	0.01	**0.04**
	India	5.7	9.4	12.8	13.2	4.0	5.07	3.15	0.38	**2.93**
	United States	17.9	22.6	25.6	27.5	2.8	2.32	1.26	0.82	**1.49**

Source: FAO. Available at: <https://bit.ly/3xAqNKM>.

Figure 4 shows the percentage share of native and planted forests in the total territory of each country. In this comparison, Brazil has the highest share of preserved areas. In the chart, the national contribution stands out more clearly when compared to other countries. Canada occupied second place, reaching 35.1 percent, followed by Germany, the United States, and France (all with a share of one-third of their territories).

FIGURE 4
Percentage share of forests (native and planted) by selected countries (2019)



Source: FAO. Available at: <https://bit.ly/3xAqNKM>.

Therefore, as Vieira Filho (2020) also seen, these numbers show that Brazil has preserved a substantial area with native forests, even with solid farming growth and relatively low land use destined for agricultural and livestock production with pastures or cropland. Brazil is committed to achieving forest restoration and preservation goals internationally. Brazilian legislation has the potential to boost the efficient use of productive resources and become an effective instrument for environmental sustainability. Even with all the criticism leveled at the country, it is clear that Brazilian contribution is substantial compared to other countries. Furthermore, Brazil is also ahead of its main competitors in environmental legislation.

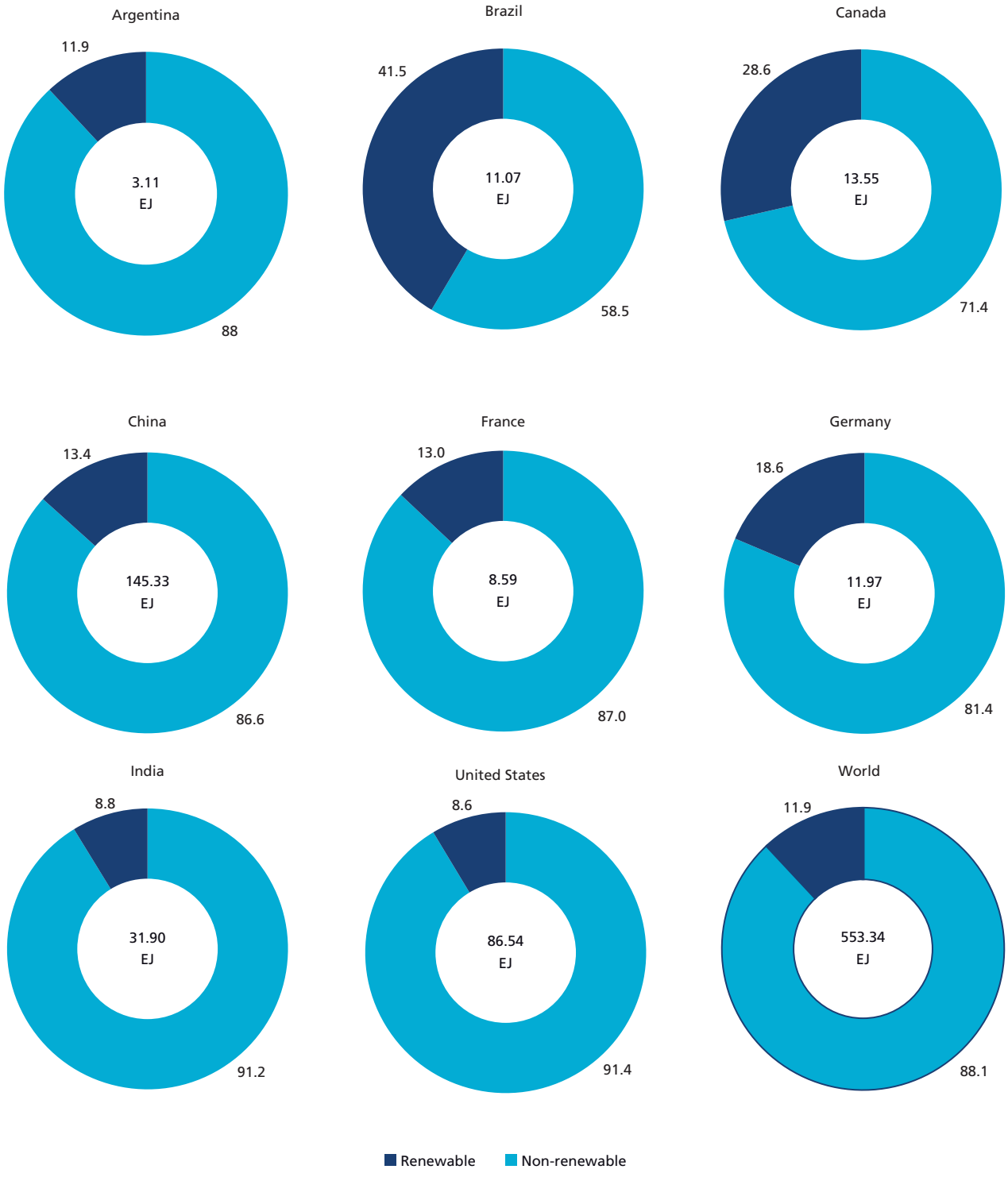
Recently, the European Union and the United States have approved the use of conservation areas. According to USDA (2022), American farmers are allowed to plant on land that is currently part of the federal conservation program without penalty to alleviate global food supply concerns. For the same reason (EC, 2022), the European Union's supply response is limited by the availability of fertile land. To enlarge production capacity, Member States exceptionally and temporarily allow European farmers to produce crops for food and feed on fallow land as a part of ecological areas while maintaining the whole level of subsidies payment. These policies go against what the international view has implemented over the past few decades.

3 ENERGY SUSTAINABILITY

3.1 Energy matrix

Figure 5 shows the percentages of energy consumption by non-renewable (oil, gas, coal, and nuclear) and renewable sources (hydroelectricity, solar, wind, geothermal, biomass, and others). Brazil has the largest share of clean energy consumption in its energy matrix in the international comparison. In Brazil, about 41.5 percent was to clean energy-related consumption in 2020. The other countries have percentages below 20 percent, except Canada, with 28.6 percent renewable energy consumption. The United States and India have the lowest shares of renewable energy consumption, less than 9 percent. The world's average renewable energy consumption is 11.9 percent, a value close to Argentina (11.9 percent), China (13.4 percent), France (13 percent), and Germany (18.6 percent).

FIGURE 5
Energy matrix: non-renewable and renewable sources by selected countries (2020)
(In percent)



Source: BP Group (2021).

Table 6 presents energy consumption per different sources, such as non-renewable (oil, gas, coal, and nuclear) and renewables (hydroelectricity, solar, wind, geothermal, biomass, and others). Brazilian energy consumption is mainly based on oil (38.4 percent) and hydropower (29.3 percent), around summed 67.7 percent up. Nonetheless, as shown before, Brazil has a large share of biofuel production (almost 12 percent). Because of hydropower and ethanol production, the Brazilian energy matrix is considered one of the cleanest globally, with renewable sources at around 41.5 percent share.

TABLE 6
Energy consumption share per different sources by selected countries (2020)
(In percent)

Country	Oil	Gas	Coal	Nuclear	Hydroelectricity	Solar	Wind	Geothermal, biomass, and other	**Consumption**
Argentina	32.9	50.2	1.0	3.0	8.6	0.4	2.7	1.2	**100.0**
Brazil	38.4	9.6	4.8	1.1	29.3	0.6	4.2	11.9	**100.0**
Canada	31.3	29.8	3.6	6.4	25.1	0.3	2.4	1.3	**100.0**
China	19.6	8.2	56.6	2.2	8.1	1.6	2.8	0.9	**100.0**
France	30.8	16.8	2.2	36.1	6.3	1.3	4.1	2.4	**100.0**
Germany	34.8	25.7	15.2	4.7	1.4	3.7	9.6	4.9	**100.0**
India	28.2	6.7	54.8	1.2	4.5	1.6	1.7	1.2	**100.0**
United States	37.1	34.1	10.5	8.4	2.9	1.4	3.4	2.2	**100.0**
World	31.3	24.7	27.2	4.3	6.9	1.4	2.5	1.8	**100.0**

Source: BP Group (2021).

Table 7 shows the energy matrix (in exajoules) by non-renewable and renewable sources, comparing the selected major agro-exporter countries. In addition, the annual growth rate was calculated for the last decade and the entire studied period. Overall, Brazilian energy consumption is not as high as that of the United States and China, but it has excellent potential for growth in renewable sources.

TABLE 7
Energy matrix per non-renewable and renewable sources by selected countries (1990-2020)
(In exajoule)

Country	Year	Non-renewable					Renewable					**Total consumption (A + B)**
		Oil	Gas	Coal	Nuclear	Total (A)	Hydroelectricity	Solar	Wind	Geothermal, biomass, and other	Total (B)	
Argentina	1990	0.83	0.71	0.04	0.07	1.66	0.18	0.00	0.00	0.00	0.18	**1.84**
	2000	0.95	1.16	0.03	0.06	2.21	0.34	0.00	0.00	0.01	0.35	**2.55**
	2010	1.18	1.52	0.05	0.07	2.81	0.38	0.00	0.00	0.04	0.40	**3.23**
	2020	1.03	1.58	0.03	0.09	2.74	0.27	0.01	0.08	0.04	0.37	**3.15**
	GR 2010-2020	-1.3	0.4	-4.1	3.4	-0.3	-3.3	161.2	79.8	-0.5	-0.7	**-0.3**
	GR 1990-2020	0.7	2.7	-1.1	0.9	1.7	1.4	-	-	12.7	2.4	**1.8**
Brazil	1990	2.47	0.11	0.40	0.02	3.01	2.07	0.00	0.00	0.28	2.11	**5.36**
	2000	3.72	0.35	0.54	0.06	4.68	3.04	0.00	0.00	0.32	3.12	**8.04**
	2010	4.54	0.99	0.61	0.14	6.27	3.79	0.00	0.02	0.87	4.11	**10.95**
	2020	4.61	1.16	0.58	0.14	6.48	3.52	0.07	0.51	1.43	4.59	**12.01**
	GR 2010-2020	0.1	1.5	-0.4	0.0	0.3	-0.7	-	37.9	5.0	1.1	**0.9**
	GR 1990-2020	2.1	8.1	1.2	6.2	2.6	1.8	-	-	5.5	2.6	**2.7**
Canada	1990	3.47	2.30	1.14	0.72	7.62	2.96	0.00	0.00	0.04	3.00	**10.62**
	2000	3.99	3.21	1.28	0.72	9.21	3.57	0.00	0.00	0.09	3.66	**12.87**
	2010	4.57	3.31	1.03	0.85	9.76	3.30	0.00	0.08	0.13	3.48	**13.27**
	2020	4.26	4.05	0.50	0.87	9.68	3.42	0.04	0.32	0.18	3.87	**13.63**
	GR 2010-2020	-0.7	2.0	-7.1	0.2	-0.1	0.4	32.3	14.6	2.7	1.1	**0.3**
	GR 1990-2020	0.7	1.9	-2.7	0.6	0.8	0.5	-	38.3	5.1	0.9	**0.8**

(Continues)

(Continued)

Country	Year	Non-renewable					Renewable					Total consumption (A + B)
		Oil	Gas	Coal	Nuclear	Total (A)	Hydroelectricity	Solar	Wind	Geothermal, biomass, and other	Total (B)	
China	1990	4.79	0.56	22.08	0.00	27.43	1.27	0.00	0.00	0.00	1.27	**28.70**
	2000	9.58	0.89	29.56	0.17	40.20	2.22	0.00	0.01	0.03	2.26	**42.45**
	2010	18.99	3.92	73.22	0.70	96.84	6.68	0.01	0.46	0.30	7.38	**104.29**
	2020	28.50	11.90	82.27	3.25	125.92	11.74	2.32	4.14	1.33	19.41	**145.46**
	GR 2010-2020	4.1	11.7	1.2	16.6	2.7	5.8	79.8	24.5	15.9	10.1	**3.4**
	GR 1990-2020	6.1	10.8	4.5	-	5.2	7.7	47.5	50.3	29.0	9.5	**5.6**
France	1990	3.88	1.09	0.80	3.14	8.91	0.54	0.00	0.00	0.02	0.56	**9.46**
	2000	4.10	1.50	0.59	4.15	10.34	0.66	0.00	0.00	0.04	0.69	**11.05**
	2010	3.53	1.78	0.48	4.02	9.82	0.59	0.01	0.09	0.14	0.73	**10.65**
	2020	2.68	1.46	0.19	3.14	7.48	0.54	0.12	0.36	0.20	1.12	**8.70**
	GR 2010-2020	-2.7	-2.0	-8.7	-2.4	-2.7	-0.8	34.9	14.5	3.5	4.3	**-2.0**
	GR 1990-2020	-1.2	1.0	-4.6	0.0	-0.6	0.0	-	48.2	8.2	2.3	**-0.3**
Germany	1990	5.53	2.29	5.51	1.53	14.86	0.17	0.00	0.00	0.01	0.19	**15.05**
	2000	5.65	2.99	3.57	1.70	13.91	0.25	0.00	0.10	0.06	0.39	**14.31**
	2010	4.89	3.17	3.23	1.32	12.60	0.20	0.11	0.36	0.43	0.99	**13.70**
	2020	4.21	3.12	1.84	0.57	9.74	0.17	0.45	1.16	0.59	2.23	**12.11**
	GR 2010-2020	-1.5	-0.2	-5.4	-8.0	-2.5	-1.7	15.1	12.4	3.2	8.5	**-1.2**
	GR 1990-2020	-0.9	1.0	-3.6	-3.2	-1.4	-0.2	42.9	28.0	13.2	8.6	**-0.7**
India	1990	2.50	0.42	4.59	0.06	7.57	0.66	0.00	0.00	0.00	0.66	**8.24**
	2000	4.61	0.91	6.88	0.16	12.56	0.77	0.00	0.02	0.02	0.80	**13.37**
	2010	6.60	2.12	12.16	0.22	21.10	1.02	0.00	0.18	0.17	1.34	**22.48**
	2020	9.02	2.15	17.54	0.40	29.10	1.45	0.52	0.54	0.37	2.80	**31.98**
	GR 2010-2020	3.2	0.1	3.7	6.2	3.3	3.6	85.8	11.4	7.9	7.6	**3.6**
	GR 1990-2020	4.4	5.6	4.6	6.3	4.6	2.6	-	28.3	25.9	4.9	**4.6**
United States	1990	33.50	18.61	19.22	6.07	77.41	2.92	0.00	0.03	0.63	3.53	**81.00**
	2000	38.35	22.62	22.63	7.94	91.54	2.73	0.01	0.06	0.80	3.46	**95.13**
	2010	35.61	23.33	20.88	7.97	87.80	2.41	0.03	0.90	1.77	4.05	**92.91**
	2020	32.54	29.95	9.20	7.39	79.08	2.56	1.19	3.03	1.93	7.46	**87.79**
	GR 2010-2020	-0.9	2.5	-7.9	-0.8	-1.0	0.6	45.3	12.9	0.9	6.3	**-0.6**
	GR 1990-2020	-0.1	1.6	-2.4	0.7	0.1	-0.4	21.2	16.9	3.8	2.5	**0.3**
World	1990	135.60	70.14	93.23	20.00	318.98	21.59	0.00	0.04	1.53	22.80	**342.14**
	2000	154.39	86.38	98.73	25.81	365.31	26.52	0.01	0.31	2.31	28.70	**394.47**
	2010	172.53	113.78	151.21	25.99	463.50	32.25	0.32	3.25	6.06	39.39	**505.38**
	2020	174.20	137.62	151.42	23.98	487.23	38.16	7.60	14.13	9.98	66.11	**557.10**
	GR 2010-2020	0.1	1.9	0.0	-0.8	0.5	1.7	37.4	15.8	5.1	5.3	**1.0**
	GR 1990-2020	0.8	2.3	1.6	0.6	1.4	1.9	28.7	22.0	6.4	3.6	**1.6**

Source: BP Group (2021).
Obs.: GR – annual average growth rate.

3.2 Electricity generation

Brazil stands out in the compared countries by looking at the electricity generation data. Table 8 presents disaggregated data by type of electricity source demanded by each country from 1990 to 2020. Brazilian electricity supply was comparable to Canada, France, and Germany, ahead of Argentina and behind the other economies. The United States and China are the top countries in generating electricity. Canada, China, Germany, India, and the United States have tried to diminish oil electricity generation. However, American and Chinese oil electricity generations are still high compared to the other countries. Brazil showed a negative growth rate of oil electricity generation in the last decade (2010-2020). The growth rates of non-renewable sources in Brazil were high, even though initially, these sources represented a small share. In this case, any increment characterizes a significant increase in the growth rate. It does not mean that Brazil is generating more electricity in absolute numbers than the other economies are. China, Brazil, and Canada are the largest producers of hydroelectric power. Chinese hydroelectricity is almost triple of Brazil and Canada.

TABLE 8
Electricity generation per non-renewable and renewable sources by selected countries (1990-2020)
(In terawatt-hour)

Country	Year	Non-renewable					Renewable					Total (A + B)
		Oil	Gas	Coal	Nuclear	Total (A)	Hydroelectricity	Wind	Solar	Geothermal, Biomass, and Other	Total (B)	
Argentina	1990	4.9	19.8	0.7	7.3	32.7	17.9	0.0	0.0	0.4	18.3	**51.0**
	2000	2.9	43.3	1.8	6.2	54.2	34.1	0.0	0.0	0.7	34.8	**89.0**
	2010	16.7	56.2	3.0	7.2	83.1	40.6	0.0	0.0	2.3	42.9	**126.0**
	2020	7.4	79.8	2.5	10.7	100.3	30.5	9.5	1.3	0.8	42.2	**142.5**
	GR 2010-2020	-7.8	3.6	-2.0	4.0	1.9	-2.8	80.8	162.7	-9.9	-0.2	**1.2**
	GR 1990-2020	1.3	4.7	4.5	1.3	3.8	1.8	-	-	2.4	2.8	**3.5**
Brazil	1990	5.1	0.3	4.6	2.2	12.3	206.7	0.0	0.0	3.9	210.6	**222.8**
	2000	15.2	4.1	11.3	6.0	36.7	304.4	0.0	0.0	7.9	312.3	**348.9**
	2010	15.7	36.5	11.7	14.5	78.4	403.3	2.2	0.0	31.9	437.4	**515.8**
	2020	7.5	56.3	22.9	15.3	102.0	396.8	57.0	8.0	56.4	518.1	**620.1**
	GR 2010-2020	-7.1	4.4	7.0	0.5	2.7	-0.2	38.6	-	5.8	1.7	**1.9**
	GR 1990-2020	1.3	18.7	5.5	6.6	7.3	2.2	-	-	9.3	3.0	**3.5**
Canada	1990	16.5	9.7	82.2	72.5	180.8	295.8	0.0	0.0	4.0	299.8	**480.6**
	2000	13.4	35.4	114.9	72.3	236.0	357.8	0.6	0.0	9.4	367.8	**603.8**
	2010	6.9	51.3	84.0	90.0	232.3	355.2	8.7	0.3	10.6	374.8	**607.0**
	2020	3.3	70.9	35.6	97.5	207.3	385.2	36.1	4.4	10.9	436.6	**643.9**
	GR 2010-2020	-7.1	3.3	-8.2	0.8	-1.1	0.8	15.3	33.0	0.3	1.5	**0.6**
	GR 1990-2020	-5.2	6.9	-2.8	1.0	0.5	0.9	38.8	-	3.4	1.3	**1.0**
China	1990	50.4	2.8	441.3	0.0	494.4	126.7	0.0	0.0	0.1	126.8	**621.2**
	2000	47.3	5.8	1,060.3	16.7	1,130.0	222.4	0.6	0.0	2.5	225.6	**1,355.6**
	2010	14.9	77.7	3,243.5	74.7	3,410.9	721.3	49.4	0.7	24.9	796.3	**4,207.2**
	2020	11.4	247.0	4,943.5	366.2	5,568.1	1,347.8	466.5	261.1	135.5	2,210.9	**7,779.1**
	GR 2010-2020	-2.6	12.3	4.3	17.2	5.0	6.5	25.2	80.8	18.5	10.8	**6.3**
	GR 1990-2020	-4.8	16.1	8.4	-	8.4	8.2	50.9	48.1	29.1	10.0	**8.8**
France	1990	-	-	-	314.1	365.0	53.9	0.0	0.0	1.9	55.8	**420.8**
	2000	-	-	-	415.2	470.6	66.4	0.0	0.0	3.0	69.4	**540.0**
	2010	-	-	-	428.5	491.1	62.7	9.9	0.6	4.9	78.2	**569.3**
	2020	-	-	-	353.8	399.3	61.3	40.6	13.1	10.6	125.6	**524.9**
	GR 2010-2020	-	-	-	-1.9	-2.0	-0.2	15.1	35.6	8.0	4.9	**-0.8**
	GR 1990-2020	-	-	-	0.4	0.3	0.4	48.8	-	5.9	2.7	**0.7**

(Continues)

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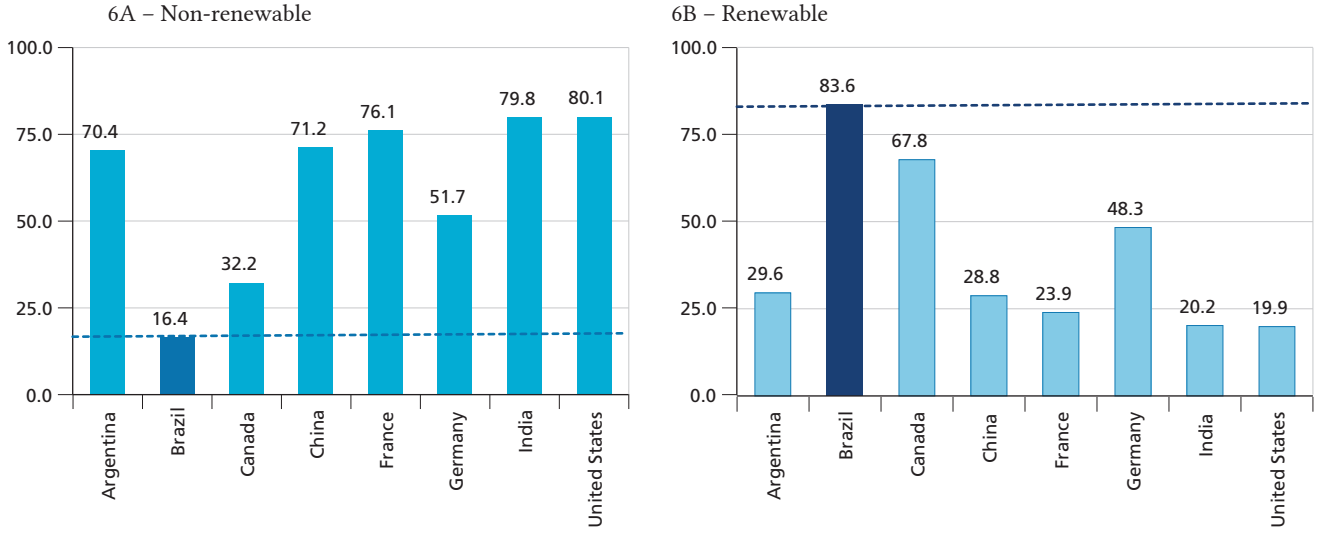
Country	Year	Non-renewable					Renewable					Total (A + B)
		Oil	Gas	Coal	Nuclear	Total (A)	Hydroe-lectricity	Wind	Solar	Geothermal, Biomass, and Other	Total (B)	
Germany	1990	10.8	35.9	311.7	152.5	510.9	17.3	0.1	0.0	1.4	18.8	**529.7**
	2000	5.9	49.2	291.4	169.6	516.1	24.9	9.5	0.1	4.7	39.2	**555.3**
	2010	8.7	89.3	262.9	140.6	501.5	21.0	38.5	11.7	34.0	105.2	**606.7**
	2020	4.3	91.9	134.8	64.4	295.4	18.6	131.0	50.6	50.8	251.0	**546.4**
	GR 2010-2020	-6.8	0.3	-6.5	-7.5	-5.2	-1.2	13.0	15.7	4.1	9.1	**-1.0**
	GR 1990-2020	-3.0	3.2	-2.8	-2.8	-1.8	0.2	28.5	43.5	12.6	9.0	**0.1**
India	1990	13.3	10.0	191.6	6.4	221.3	66.4	0.0	0.0	0.0	66.5	**287.8**
	2000	29.2	56.0	390.2	15.8	491.1	77.0	1.6	0.0	1.7	80.3	**571.4**
	2010	10.8	118.0	643.0	23.1	794.9	108.7	19.5	0.1	14.3	142.6	**937.5**
	2020	4.9	70.8	1,125.2	44.6	1,245.5	163.6	60.4	58.7	32.1	314.8	**1,560.3**
	GR 2010-2020	-7.7	-5.0	5.8	6.8	4.6	4.2	12.0	86.9	8.4	8.2	**5.2**
	GR 1990-2020	-3.3	6.8	6.1	6.7	5.9	3.1	28.8	-	25.2	5.3	**5.8**
United States	1990	136.0	400.8	1,725.2	607.2	2,869.2	292.3	2.8	0.4	57.5	352.9	**3,222.1**
	2000	119.6	646.3	2,129.3	793.6	3,688.7	272.8	5.6	0.5	66.6	345.5	**4,034.2**
	2010	39.9	1,062.0	1,998.5	849.4	3,949.8	257.3	95.6	3.0	75.1	431.0	**4,380.8**
	2020	18.8	1,738.4	844.1	831.5	3,432.8	288.7	340.9	134.0	76.8	840.4	**4,273.2**
	GR 2010-2020	-7.2	5.1	-8.3	-0.2	-1.4	1.2	13.6	46.2	0.2	6.9	**-0.2**
	GR 1990-2020	-6.4	5.0	-2.4	1.1	0.6	0.0	17.3	21.7	1.0	2.9	**0.9**

Source: BP Group (2021).
Obs.: GR – annual average growth rate.

Overall, there is a race for greater energy diversification that searches for a clean matrix. Even though Brazil presents an increase in non-renewable electricity sources, the general picture shows that the national outcome is better in sustainability than its main competitors (figure 6). Renewable sources accounted for 83.6 percent of total electricity generation in Brazil, the highest share in this international comparison. Non-renewable sources are higher than 50 percent of total electricity generated in the United States, India, France, China, Argentina, and Germany, in this order. In Brazil, non-renewable sources represented only 16.4 percent of the totality, the smallest share in 2020 amongst the compared countries.

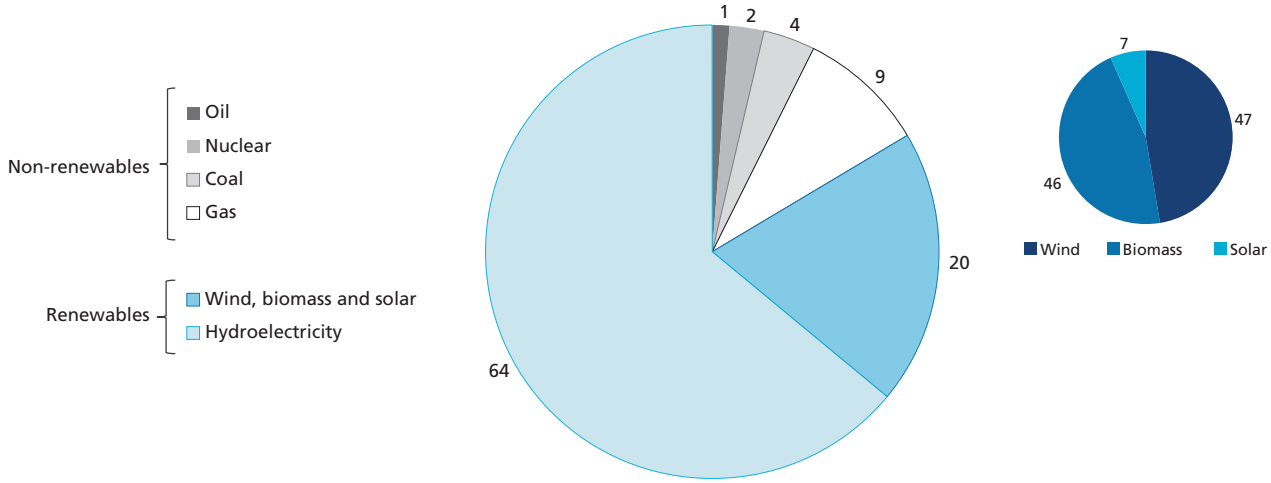
FIGURE 6
Non-renewable and renewable electricity share by selected countries (2020)
(In percent)



Source: BP Group (2021).

Finally, figure 7 shows disaggregated Brazilian electricity sources in 2020. On the one hand, the oil share represented only 1 percent, nuclear energy power accounted for just 2 percent, coal source was 4 percent, and natural gas was 9 percent. The complete sources of non-renewable were less than 17 percent of the Brazilian electricity mix. On the other hand, renewable sources were dominant. Hydropower represented 64 percent of the total. By analyzing the new sources of electricity generation in the past few years, wind, biomass, and solar inputs accounted for roughly 20 percent. Wind electricity represented 47 percent, biomass 46 percent, and solar 7 percent of this share. Looking at these statistics, it is clear that Brazil has enormous potential to be at the technological frontier soon.

FIGURE 7
Brazilian electricity sources (2020)
(In percent)



Source: BP Group (2021).

The challenges of the Brazilian electricity sector are enormous. Several actions were taken. It was implemented in 2020 the Law No. 14,052,[5] which mitigated the hydrological risk and brought a better legal and regulatory framework to the market. The Law No. 14,120 of 2021[6] reduced subsidies for alternative sources and enabled more effective market opening for the retail sector. Likewise, the Brazilian government has been working with the National Congress to approve the Bill No. 414 of 2021,[7] which seeks to improve the regulatory and commercial model of the electricity sector. The proposal is to bring a series of advances to expand free-market competition. It is essential in this context to keep leadership in the production and consumption of clean energy.

3.3 Biofuel

Table 9 shows that ethanol production is concentrated in the United States and Brazil. In 2021, these two markets accounted for approximately 75.6 percent of the world's output. The European Union accounted for just 4.4 percent of the world's total ethanol production. China, India, Canada, and Argentina played marginal roles in this promising market.

TABLE 9
Ethanol production by selected countries (2016-2021)

Country	2016		2017		2018		2019		2020		2021	
	1 million gallons	Percent	1 million gallons	Percent	1 million gallons	Percent	1 million gallons	Percent	1 million gallons	Percent	1 million gallons	Percent
Argentina	240	0.8	290	1.0	290	0.9	290	0.9	210	0.7	260	0.9
Brazil	6,870	24.2	6,760	23.1	8,080	26.0	8,790	27.6	8,080	28.1	7,500	25.2
Canada	450	1.6	460	1.6	460	1.5	500	1.6	430	1.5	440	1.5
China	730	2.6	850	2.9	810	2.6	1,010	3.2	930	3.2	860	2.9
India	270	1.0	210	0.7	420	1.4	470	1.5	510	1.8	820	2.8

(Continues)

5. Available at: <https://bit.ly/3NqIm56>.
6. Available at: <https://bit.ly/3zl9Ch3>.
7. Available at: https://bit.ly/3ti28Yz>. The debate on this bill was discussed in the technical report written by Gutierrez (2022).

(Continued)

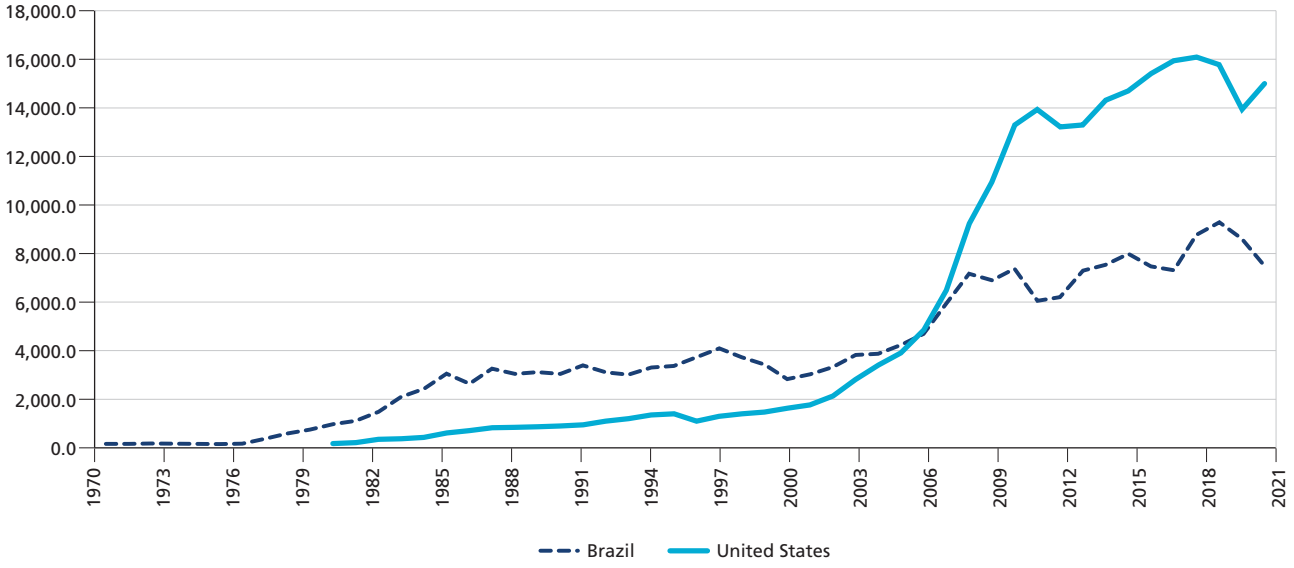
Country	2016		2017		2018		2019		2020		2021	
	1 million gallons	Percent	1 million gallons	Percent	1 million gallons	Percent	1 million gallons	Percent	1 million gallons	Percent	1 million gallons	Percent
United States	15,413	54.3	15,936	54.5	16,091	51.7	15,778	49.6	13,941	48.5	15,000	50.4
Others (A + B + C)	2,197	7.7	2,364	8.1	2,479	8.0	2,492	7.8	2,309	8.0	2,430	8.2
European Union (A)	1,240	4.4	1,320	4.5	1,360	4.4	1,380	4.3	1,260	4.4	1,300	4.4
Thailand (B)	330	1.2	380	1.3	390	1.3	430	1.4	390	1.4	390	1.3
Rest of the world (C)	627	2.2	664	2.3	729	2.3	682	2.1	659	2.3	740	2.5
Total	**28,367**	**100.0**	**29,234**	**100.0**	**31,109**	**100.0**	**31,822**	**100.0**	**28,719**	**100.0**	**29,740**	**100.0**

Source: Renewable Fuels Association (RFA). Available at: <https://bit.ly/3NrA4Ki>.

Brazilian ethanol production began in the 1970s, and the main goal was to replace imported oil consumption. This decade was marked by two oil shocks, which raised the oil price in the world. Because of the rise in oil costs, ethanol became a vital energy source in Brazil. The Brazilian government created a national program to produce ethanol from sugarcane. In the United States, ethanol production began in the 1980s based on corn. As the United States had a large oil production, there initially was no concern with ethanol production.

In the 1990s, with few incentives, Brazilian production stabilized. However, climate change concerns increased. There was a solid appeal to reduce the consumption of fossil fuels in the world. Furthermore, in 2003, the total flex car was launched, which could mix gasoline and ethanol. There was a new stimulus to produce ethanol in this context. Brazil and the United States were leading the market at that moment and continued in the years ahead. In 2006, American ethanol production surpassed Brazilian production for the first time. Figure 8 shows the annual evolution of ethanol production in these two countries over time.

FIGURE 8
Brazilian and American annual ethanol production (1970-2021)
(In 1 million gallons)



Sources: RFA (available at: <https://bit.ly/3NrA4Ki>); and Ipeadata (available at: <http://ipeadata.gov.br>).
Obs.: 1 gallon = 3.785 liters.

In terms of world production, although Brazil is the third-largest producer of corn, the relevant raw material in the Brazilian production of biofuel is sugarcane. In Brazil, corn represents only 4.5 percent of the national ethanol production. In the United States, 95 percent of ethanol production is corn-based. In the European Union, ethanol is produced from wheat, sugar beet, and corn, and corn is the primary input representing 32 percent of the total production.

As seen in table 10, the main reason for the dominance of ethanol production from sugarcane in Brazil is the difference between crop yields. Corn produces about 24 percent of the volume of sugarcane-based ethanol per hectare planted in Brazil, and in the United States, this percentage is about 40 percent. Therefore, comparing Brazil versus the United States, the productive difference between Brazilian sugarcane and American corn is roughly 45 percent. Furthermore, in Brazil, the ethanol cost based-corn is higher than the ethanol cost based-sugarcane.

TABLE 10
Ethanol productivity by country

Country	Crop	Production share of ethanol per crop (percent)	Production in 1 ha (1 ton)	Raw material production (1 ton)[1]	Ethanol (1 gallon per ton)[2]	Ethanol production (1 gallon)
			(1)	(2)	(3)	(2.3)
Brazil	Sugarcane	95.5	75.6	75.6	22.5	1,697.8
	Corn	4.5	5.7	3.5	116.3	405.8
United States	Sugarcane	5.0	85.4	85.4	22.5	1,917.8
	Corn	95.0	10.8	6.6	116.3	768.9

Source: FAO. Available at: <https://bit.ly/3xAqNKM>.
Notes: [1] Sugarcane = 100 percent; and corn = 61 percent.
[2] Educated guess.

Sugarcane and corn productions are very different value chains. A simple comparison between crop productivity is not enough to assess business attractiveness. It is necessary to consider the value of the co-products (electric energy from bagasse and cellulosic ethanol) and the totality of production costs (including opportunity costs). The attractiveness of producing ethanol from sugarcane depends on international sugar prices. Ethanol production competes with sugar, and when sugar prices are high, fuel becomes less attractive. In Brazil, about 45 percent to 50 percent of the raw material has been used for sugar production over the last years. Cellulosic ethanol is not yet economically viable in Brazil, mainly due to the costs of the enzymes used in the process.

Table 11 presents a simple comparison between corn and sugarcane production in Brazil and the United States. Yields are higher in the United States than in Brazil. However, Brazil's average annual yield growth is faster than the American market. So it could be suggested that a gap reduction in productivity between these two countries still exists over time. Finally, it is imperative to mention that corn is a central input for food production, which is not valid for sugarcane production. Consequently, several vested interests in corn-based fuel production must be considered.

TABLE 11
Corn and sugar cane production in Brazil and the United States (1990-2020)

Product	Country	Variable	Year				Average annual rate of growth (percent)			
			1990	2000	2010	2020	1st decade (1990-2000)	2nd decade (2000-2010)	3rd decade (2010-2019)	**Total (1990-2019)**
Corn	Brazil	Production (1 Mton)	21.3	32.3	55.4	104.0	4.23	5.53	6.50	**5,42**
		Area harvested (1 Mha)	11.4	11.9	12.7	18.3	0.43	0.64	3.71	**1,58**
		Yield (ton/ha)	1.9	2.7	4.4	5.7	3.79	4.85	2.69	**3,78**
	United States	Production (1 Mton)	201.5	251.9	315.6	360.3	2.25	2.28	1.33	**1,96**
		Area harvested (1 Mha)	27.1	29.3	33.0	33.4	0.79	1.18	0.12	**0,70**
		Yield (ton/ha)	7.4	8.6	9.6	10.8	1.45	1.09	1.21	**1,25**
	Δ production Brazil and United States (1 Mton)		-180,2	-219.5	-260.3	-256.3	1.99	1.72	-0.15	**1.18**

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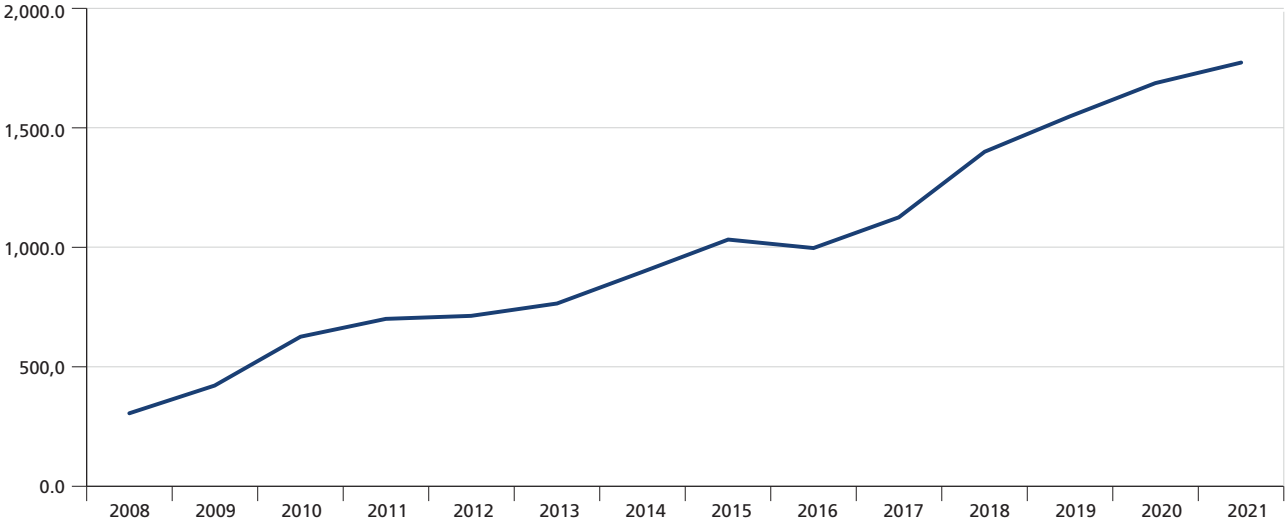
Product	Country	Variable	Year				Average annual rate of growth (percent)			
			1990	2000	2010	2020	1st decade (1990-2000)	2nd decade (2000-2010)	3rd decade (2010-2019)	**Total (1990-2019)**
Sugar cane	Brazil	Production (1 Mton)	262.7	326.1	717.5	757.1	2.19	8.20	0.54	**3,59**
		Area harvested (1 Mha)	4.3	4.8	9.1	10.0	1.18	6.57	0.99	**2,88**
		Yield (ton/ha)	61.5	67.9	79.0	75.6	1.00	1.53	-0.44	**0,69**
	United States	Production (1 Mton)	25.5	36.1	24.8	32.7	3.53	-3.68	2.81	**0,83**
		Area harvested (1 Mha)	0.3	0.4	0.4	0.4	2.66	-1.61	0.77	**0,59**
		Yield (ton/ha)	79.4	86.4	69.9	85.4	0.85	-2.10	2.02	**0,24**
	Δ production Brazil and United States (1 Mton)		237,2	290.0	692.6	724.4	2.03	9.10	0.45	**3.79**

Source: FAO. Available at: <https://bit.ly/3xAqNKM>.

Moreover, in 2004, Brazil created the National Program for Biodiesel Production.[8] In 2005, biodiesel was introduced into the Brazilian energy matrix. The raw materials used in production came from different crops, mostly soybean, corn, and castor beans. However, other agricultural inputs that permit production were also used, such as sunflower, cottonseed, canola, palm oil, and even those of animal origin as beef tallow, chicken, and swine fat. Since then, biodiesel production has started to increase. In 2008, biodiesel production was just 308.4 million gallons. In 2021, Brazil produced 1,786 million gallons, and Brazilian production has grown since 2008 at an annual growth rate of 14.5 percent. Compared to ethanol production, in 2021, it represented roughly 24 percent of the national ethanol market. The evolution of biodiesel production can be seen in figure 9.

FIGURE 9
Brazilian biodiesel production (2008-2021)
(In 1 million gallons)



Source: ANP. Available at: <https://bit.ly/3xdGYvC>.

The Brazilian government has a resilient tradition of encouraging the mixture of ethanol in gasoline as an intervention to develop the production sector. This policy also generates positive externalities to the environment. In 2022, the National Energy Policy Council (CNPE) established the mandatory blending content of biodiesel into the fossil diesel oil at 10 percent. Regarding the ethanol market, since 2015, the blending share of ethanol fuel in regular gasoline has been registered at 27 percent, while in premium gasoline, it has been established at 25 percent.

8. For more information on Law No. 11,097 of 2005, see: <https://bit.ly/3mlnwrU>.

On the opposite side, the temporary flexibility to enlarge agricultural production in the European Union will allow farmers to adjust and expand their cropping plans in 2022. According to EC (2022), the Commission supports the Member States in reducing biofuels' blending proportion, which could lead to a pressure decrease on the markets for food and feed commodities. This action can reduce agricultural land used for the production of biofuel feedstocks. Once again, this kind of policy is an intervention against production with sustainable purposes.

3.4 Production per unit of GHG emissions

Table 12 presents GHG emissions by sectors in Brazil from 1990 to 2016. Statistics show an increase in emissions in practically all sectors, except for land-use change. In the second decade, there was a deforestation decrease in the Amazon. In 2004, the Prevention and Control of Deforestation Plan was implemented in the Amazon (PPCDAM). This drop provided a relative increase in other sectors´ emissions in the Brazilian economy (Lapola et al., 2014; Vieira Filho and Gasques, 2016). In this sense, the agriculture sector began to show a superior share of total emissions. In 1990, the land-use change represented roughly 60 percent of the total emissions, and agricultural emissions were only 21.8 percent. In 2016, deforestation drop reduced its share to 27.1 percent, and the agriculture sector showed 33.2 percent of the total net emissions. The average annual growth rate was negative by looking at total net emissions, even though agricultural emissions have increased. The highest annual growth was observed in the waste sector with 3.6 percent.

From 1990 to 2016, agricultural GHG emissions increased from 329.5 to 487 billion tons of CO2 equivalent at an average annual rate of 1.5 percent. The leading subsector responsible for that emission was enteric fermentation from beef production (around 60 percent of the total agricultural emissions). Public policies that promote investment in the livestock production processes (such as pasture recovery, suitable pasture management, food diet that increases weight and reduces animal slaughter age) present a substantial potential for GHG mitigation (Vieira Filho, 2017; Costa Junior et al., 2019).

Brazilian Agricultural Research Corporation (Embrapa) has developed the concept of "carbon neutral beef" that aims to support the implementation of more sustainable cattle systems (Alves, Almeida and Laura, 2017). Forestry was introduced into production to neutralize methane emitted by cattle. Integrated systems can ensure more added value for the beef production chain.[9] Research in this field also aims to spread scope and scale economies. In sum, it optimizes the use of inputs and increases production with fewer methane emissions.

9. Law No. 12,805 from 2013 established the National Crop-Livestock-Forest Integration Policy.

TABLE 12

GHG emissions and respective share by sectors in Brazil (1990-2016)

Sector		1990		1995		2000		2005		2010		2016		Average annual rate of growth (percent)			
		Gt Co2e	Percent	Gt Co2e	Percent	Gt Co2e	Percent	Gt Co2e	Percent	Gt Co2e	Percent	Gt Co2e	Percent	1st decade (1990-2000)	2nd decade (2000-2010)	3rd decade (2010-2016)	**Total (1990-2019)**
1	Energy	192.8	12.8	231.0	8.7	288.2	14.8	313.4	12.8	374.7	30.6	423.6	28.9	4.1	2.7	2.1	**3,1**
2	Industrial processes	53.6	3.5	64.0	2.4	73.8	3.8	78.9	3.2	83.6	6.8	93.4	6.4	3.3	1.3	1.8	**2,2**
3	Agriculture	329.5	21.8	359.2	13.5	370.1	19.0	438.0	17.9	458.1	37.4	487.0	33.2	1.2	2.2	1.0	**1,5**
3.1	Enteric fermentation	213.7	14.2	233.4	8.8	235.7	12.1	278.1	11.4	278.3	22.7	282.7	19.3	1.0	1.7	0.3	**1,1**
3.2	Manure management	14.3	0.9	16.0	0.6	15.3	0.8	17.7	0.7	19.6	1.6	22.6	1.5	0.7	2.5	2.4	**1,8**
3.3	Rice cultivation	7.0	0.5	8.7	0.3	7.7	0.4	8.1	0.3	8.1	0.7	8.4	0.6	1.1	0.5	0.6	**0,7**
3.4	Agricultural soils	83.0	5.5	92.6	3.5	99.1	5.1	121.9	5.0	136.6	11.1	153.1	10.4	1.8	3.3	1.9	**2,4**
3.5	Field burning	1.7	0.1	1.8	0.1	1.6	0.1	2.1	0.1	1.9	0.2	0.5	0.0	-0.4	1.4	-19.5	**-4,5**
3.6	Liming	9.1	0.6	5.8	0.2	9.4	0.5	8.1	0.3	11.3	0.9	15.8	1.1	0.3	1.8	5.8	**2,1**
3.7	Urea application	0.6	0.0	0.9	0.0	1.2	0.1	1.9	0.1	2.4	0.2	3.9	0.3	6.6	7.2	8.3	**7,2**
4	Land-use change and forestry	907.5	60.1	1,966.8	74.1	1,175.0	60.3	2,085.7	85.3	252.5	20.6	397.4	27.1	2.6	-14.3	7.8	**-3,1**
5	Waste	26.2	1.7	34.3	1.3	42.6	2.2	51.6	2.1	56.7	4.6	66.0	4.5	5.0	2.9	2.6	**3,6**
Total (net emissions)		**1,509.6**	**100.0**	**2,655.2**	**100.0**	**1,949.6**	**100.0**	**2,445.9**	**100.0**	**1,225.6**	**100.0**	**1,467.3**	**100.0**	**2.6**	**-4.5**	**3.0**	**-0.1**

Source: Brasil (2021b).

Livestock production is more responsible for a vast proportion of GHG emissions than the entire global transportation sector, as Pitesck, Stackhouse and Mitloehner (2009) mentioned. However, these authors showed that the impact of livestock on climate change has arrived at much different GHG estimates associated with direct livestock emissions (enteric fermentation and manure). If the methodology accounts for emissions and sinks, the livestock sector can potentially diminish its share of total net emissions. Stackhouse-Lawson et al. (2012) simulated integrated agriculture and livestock model. Crop growth, feed production, animal growth, and the return of manure nutrients back to the land were included to predict the environmental and economic impacts. Livestock emissions are determined by summing the total emissions from all included variables. All sources and sinks of GHG emissions were expected. This simulation study indicated beef production systems where mitigation strategies can most effectively reduce. Scope and scale economies in livestock production can reduce total net emissions from the agriculture sector. Table 13 presents GHG emissions and respective shares by sectors and selected countries. Brazil has the lowest percentage in the energy sector. Nonetheless, Brazilian agricultural emission proportion to the total net emission is higher in the international comparison. The agriculture sector is part of the solution to diminish total emissions, as sinks can be included in the accounting equation. So Brazil appears to be the country that has the best structure for reducing GHG emissions.

TABLE 13

GHG emissions and respective share by sectors and selected countries (1990-2019)

Country	Sector	Year (Gt CO2e)				Annual growth rate	Share (percent)			
		1990	2000	2010	2019		1990	2000	2010	2019
Argentina	Energy	103.6	132.0	177.1	183.4[3]	2.0	47.9	55.3	39.6	42.7
	Industrial processes	8.5	11.1	14.9	15.3[3]	2.1	3.9	4.7	3.3	3.6
	Agriculture	109.6	124.9	120.6	119.5[3]	0.3	50.7	52.3	26.9	27.8
	Land-use change and forestry	-14.8	-43.3	115.1	90.5[3]	-	-6.8	-18.1	25.7	21.1
	Waste	9.4	14.0	19.9	20.8[3]	2.8	4.3	5.9	4.4	4.8
	Total (net emissions)	216.3	238.7	447.6	429.5[3]	2.4	100.0	100.0	100.0	100.0
Brazil	Energy	192.8	288.2	374.7	423.6[1]	2.8	12.8	14.8	30.6	28.9
	Industrial processes	53.6	73.8	83.6	93.4[1]	1.9	3.5	3.8	6.8	6.4
	Agriculture	329.5	370.1	458.1	487.0[1]	1.4	21.8	19.0	37.4	33.2
	Land-use change and forestry	907.5	1,175.0	252.5	397.4[1]	-2.8	60.1	60.3	20.6	27.1
	Waste	26.2	42.6	56.7	66.0[1]	3.2	1.7	2.2	4.6	4.5
	Total (net emissions)	1,509.6	1,949.6	1,225.6	1,467.3[1]	-0.1	100.0	100.0	100.0	100.0
Canada	Energy	471.6	591.7	569.4	589.3	0.8	86.6	83.1	81.9	79.6
	Industrial processes	57.0	54.1	50.7	54.3	-0.2	10.5	7.6	7.3	7.3
	Agriculture	46.9	57.0	55.1	59.1	0.8	8.6	8.0	7.9	8.0
	Land-use change and forestry	-56.8	-21.7	-7.3	9.9	-	-10.4	-3.1	-1.1	1.3
	Waste	26.0	30.7	27.7	27.6	0.2	4.8	4.3	4.0	3.7
	Total (net emissions)	544.7	711.8	695.5	740.1	1.1	100.0	100.0	100.0	100.0
China	Energy	3,007.8[4]	4,625.4[5]	8,282.8	9,558.6[2]	4.1	82.4	84.9	86.7	85.5
	Industrial processes	282.6[4]	576.8[5]	1,299.9	1,717.0[2]	6.4	7.7	10.6	13.6	15.4
	Agriculture	605.1[4]	696.5[5]	828.4	829.8[2]	1.1	16.6	12.8	8.7	7.4
	Land-use change and forestry	-407.5[4]	-586.7[5]	-993.2	-1,114.8[2]	3.5	-11.2	-10.8	-10.4	-10.0
	Waste	162.1[4]	137.6[5]	132.2	194.8[2]	0.6	4.4	2.5	1.4	1.7
	Total (net emissions)	3,650.1[4]	5,449.6[5]	9,550.2	11,185.4[2]	3.9	100.0	100.0	100.0	100.0

(Continues)

(Continued)

Country	Sector	Year (Gt CO2e)				Annual growth rate	Share (percent)			
		1990	2000	2010	2019		1990	2000	2010	2019
France	Energy	368.8	383.7	361.8	303.3	-0.7	70.2	71.7	75.7	73.5
	Industrial processes	78.9	65.0	54.5	47.7	-1.7	15.0	12.2	11.4	11.6
	Agriculture	81.8	82.2	76.1	73.5	-0.4	15.6	15.4	15.9	17.8
	Land-use change and forestry	-21.6	-17.2	-35.6	-30.4	1.2	-4.1	-3.2	-7.4	-7.4
	Waste	17.6	21.4	21.1	18.4	0.2	3.4	4.0	4.4	4.5
	Total (net emissions)	525.5	535.3	477.9	412.6	-0.8	100.0	100.0	100.0	100.0
Germany	Energy	1,037.0	870.2	801.5	677.4	-1.5	81.4	85.1	86.0	85.4
	Industrial processes	96.8	77.8	62.6	61.4	-1.6	7.6	7.6	6.7	7.7
	Agriculture	76.5	66.1	63.2	61.8	-0.7	6.0	6.5	6.8	7.8
	Land-use change and forestry	24.9	-20.6	-9.8	-16.5	-	2.0	-2.0	-1.1	-2.1
	Waste	38.2	28.5	14.5	9.2	-4.8	3.0	2.8	1.6	1.2
	Total (net emissions)	1,273.4	1,022.1	932.0	793.3	-1.6	100.0	100.0	100.0	100.0
India	Energy	743.8[4]	1,027.0	1,510.1	2,129.7[1]	3.7	60.5	78.9	80.1	84.1
	Industrial processes	102.7[4]	88.6	171.5	226.4[1]	2.8	8.4	6.8	9.1	8.9
	Agriculture	344.5[4]	355.6	390.2	408.0[1]	0.6	28.0	27.3	20.7	16.1
	Land-use change and forestry	14.3[4]	-222.6	-252.5	-307.7[1]	-	1.2	-17.1	-13.4	-12.2
	Waste	23.2[4]	52.6	65.1	75.3[1]	4.1	1.9	4.0	3.5	3.0
	Total (net emissions)	1,228.5[4]	1,301.2	1,884.3	2,531.7[1]	2.5	100.0	100.0	100.0	100.0
United States	Energy	5,325.6	6,176.6	5,861.7	5,392.3	0.0	96.1	95.6	94.4	93.5
	Industrial processes	345.6	394.4	362.5	373.7	0.3	6.2	6.1	5.8	6.5
	Agriculture	555.3	556.9	596.3	628.6	0.4	10.0	8.6	9.6	10.9
	Land-use change and forestry	-900.8	-854.0	-783.9	-789.2	-0.5	-16.3	-13.2	-12.6	-13.7
	Waste	216.2	185.8	170.5	163.7	-1.0	3.9	2.9	2.7	2.8
	Total (net emissions)	5,541.9	6,459.7	6,207.2	5,769.1	0.1	100.0	100.0	100.0	100.0

Source: United Nations Climate Change (UNCC). Available at: <https://bit.ly/3GWCoX7>.
Notes: [1] Numbers of 2019.
[2] Numbers of 2014.
[3] Numbers of 2012.
[4] Numbers of 1994.
[5] Refers to average number between 1994 and 2005.

Table 14 shows production per emission unit. The results showed that the food production of 1 kg today generates fewer emissions than in the past, and Brazil has led this global race for more sustainable production. The Brazilian economy had the best growth rate of the indicator based on production per total GHG emissions in agricultural and livestock production. Concerning output per agricultural GHG emissions, Brazil achieved the best growth rate again from 1990 to 2020. In livestock production, the Brazilian performance was inferior to the result found in Argentina and China regarding the output per agricultural GHG emissions. When comparing Brazil with other countries, there is no doubt that Brazilian behavior contributes to the sustainability of production. These results prove that policies that foster science-based agricultural knowledge and increase productivity contribute to the output growth per unit of GHG emissions.

TABLE 14
Agricultural and livestock production per unit of GHG emissions (1990-2020)

GHG emission	Sector	Country	Year (ton per CO2e)				Annual growth rate (percent)			
			1990	2000	2010	2020	1st decade	2nd decade	3rd decade	1990-2020
Production per total GHG emissions	Livestock	Argentina	41.0	32.2	25.2	31.2	-2.39	-2.43	2.15	**-0.91**
		Brazil	16.4	19.9	23.0	51.9	1.94	1.49	8.46	**3.92**
		Canada	4.8	5.9	4.3	5.8	2.03	-3.08	2.97	**0.61**
		China	4.1	3.5	1.0	0.8	-1.60	-11.65	-2.71	**-5.43**
		France	12.8	12.3	14.3	15.7	-0.45	1.58	0.94	**0.69**
		Germany	5.3	4.8	4.7	4.8	-0.86	-0.25	0.29	**-0.27**
		India	20.2	13.2	7.8	6.0	-4.16	-5.17	-2.56	**-3.97**
		United States	5.1	4.9	5.2	6.0	-0.52	0.69	1.40	**0.52**
	Agriculture	Argentina	216.9	295.6	299.7	440.8	3.15	0.14	3.94	**2.39**
		Brazil	243.3	278.5	458.8	774.1	1.36	5.12	5.37	**3.93**
		Canada	111.6	100.5	79.8	142.4	-1.04	-2.28	5.97	**0.82**
		China	285.2	274.9	154.6	156.1	-0.37	-5.59	0.10	**-1.99**
		France	249.5	265.1	313.0	307.6	0.61	1.68	-0.17	**0.70**
		Germany	83.4	106.6	103.2	120.7	2.49	-0.32	1.57	**1.24**
		India	546.3	481.5	328.2	324.9	-1.25	-3.76	-0.10	**-1.72**
		United States	91.5	94.2	107.4	122.1	0.29	1.32	1.29	**0.97**
Production per agricultural GHG emissions	Livestock	Argentina	99.7	91.3	92.9	94.9	-0.88	0.17	0.22	**-0.16**
		Brazil	79.1	94.5	98.7	148.6	1.79	0.43	4.18	**2.12**
		Canada	63.1	81.2	76.0	74.6	2.56	-0.66	-0.18	**0.56**
		China	20.1	22.0	14.4	13.4	0.93	-4.14	-0.71	**-1.33**
		France	70.7	70.9	76.0	77.1	0.03	0.70	0.14	**0.29**
		Germany	67.5	64.9	64.0	64.5	-0.38	-0.14	0.06	**-0.15**
		India	36.0	32.0	28.9	27.9	-1.16	-1.00	-0.37	**-0.85**
		United States	79.4	85.1	84.4	90.2	0.69	-0.08	0.67	**0.42**
	Agriculture	Argentina	526.7	837.7	1104.2	1341.8	4.75	2.80	1.97	**3.17**
		Brazil	1,175.0	1,325.2	1,965.5	2,216.5	1.21	4.02	1.21	**2.14**
		Canada	1,464.3	1,388.2	1,410.1	1,844.7	-0.53	0.16	2.72	**0.77**
		China	1,387.8	1,725.4	2,194.3	2,716.0	2.20	2.43	2.16	**2.26**
		France	1,375.1	1,532.6	1,659.0	1,505.6	1.09	0.80	-0.97	**0.30**
		Germany	1,070.4	1,436.3	1,406.0	1,607.3	2.98	-0.21	1.35	**1.36**
		India	973.3	1,167.5	1,223.2	1,512.8	1.84	0.47	2.15	**1.48**
		United States	1,417.1	1,645.4	1,737.0	1,836.4	1.50	0.54	0.56	**0.87**

Sources: FAO (available at: <https://bit.ly/3xAqNKM>); and World Bank (available at: <https://bit.ly/3GVTKDp>).

Although most research has focused on mitigation through improved productivity, Silva et al. (2016) developed an optimization model for beef production. This model was parameterized for the Brazilian Savanna encompassing pasture degradation and recovery processes, animal and deforestation emissions, soil organic carbon dynamics, and upstream life-cycle inventory. The results showed that economic return was maximized considering two alternative scenarios: decoupled livestock–deforestation, assuming baseline deforestation rates controlled by the effective policy; and coupled livestock–deforestation, where shifting beef demand alters deforestation rates. Under the controlled scenario, boosted consumption led to more productive beef systems, associated with more production per unit of CO2 equivalent emissions. Moreover, reduced production led to less efficient systems with decreased carbon stocks. Under uncontrolled deforestation, increased production leads to 60 percent higher emissions than in the first scenario.

4 CONCLUDING REMARKS

Brazil has the highest growth rate in agricultural productivity, and the maintenance of this growth must be related to investments in science and technology. Most Brazilian agriculture is highly based on technology. *There is no doubt that Brazil is at the core of sustainable agribusiness production worldwide and has much to contribute to the global supply of food and energy.*

The forest-sparing effect appears as the largest among the countries compared. These results, which align production with sustainability, need to be better explored and disseminated. The main competitors in the agro-export market are some economies with lower sustainable production indicators.

Brazilian production per unit of emission continues to grow. In part, the technical change advance is responsible, on the one hand, and investments in low carbon production, on the other. Brazil has the most extensive coverage with native vegetation in its territory and has an agribusiness with high productivity. Brazil has been complying with the agreed contribution to reducing GHG emissions regarding the goals established internationally. It is also necessary to minimize illegal deforestation, regulate the carbon market and encourage low-carbon agricultural project investments.

In the production of biofuels, Brazil is, with the United States, the primary reference in the production of ethanol. Brazilian production has a higher yield per hectare of the planted area than the American economy. It is necessary to explore this market. A transition of the energy matrix in the world to a low carbon economy increasingly requires clean energy.

The world is dependent on non-renewable energy sources. On the contrary, Brazil stands out for having the cleanest energy matrix. It is interesting for Brazil to maintain this vanguard in clean energy consumption and invest in existing potential.

World leadership in clean energy production is very significant nowadays. The search for a larger share of renewable energy sources is shaping policies worldwide. Brazil is ahead of its main international competitors. Prospects for oil are not favorable. It is inexorable that oil consumption has been decreasing over time, while the growth of renewable sources in Brazil (wind, solar, and biomass, mainly) has shown unprecedented rates.

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