List of Figures

Figure 1.1	Changing nature of global markets: more diverse energy mix, increased competition, and greater customer choice. Source: BP (2022)	26
Figure 1.2	Modern bioenergy increases sharply, supporting the transition to a low-carbon energy system. Source: BP (2022)	26
Figure 1.3	Biofuels final transport energy demand by fuel type in the IEA 2DS, 2060. Source: IEA (2017)	28
Figure 1.5	Historical U.S. fuel ethanol production. U.S. Energy Information Administration. Source: RFA (2022)	30
Figure 1.6	Biodiesel and HVO Production and Key Markets, 2019 – 2025. Source: IEA (2021c)	35
Figure 1.7	Global production capacity of advanced biofuels (operational). Source: CIT (2020)	36
Figure 1.8	Sources of hydrogen production, 2020. Source: IEA (2021e)	43
Figure 1.9	Hydrogen: A key part of future energy systems. Source: IRENA (2020)	44
Figure 1.10	Grain is mainly used for feed production. Source: UFOP (2022)	47
Figure 1.1	1 Biofuels take up little space. Source: UFOP (2022)	47
Figure 1.12	2 Brazilians per capita CO_2 emissions. Source: MME (2021)	48

Figure 2.1	The concentration of sugarcane juice prior to crystallization. Source: Leandro Vilar	52
Figure 2.2	(a) sugar loaf obtained from sugar crystallization; (b) The Sugarloaf Mountain in Rio	52
Figure 2.3	Ethanol content in Brazilian gasoline between 1930 to 2010. Source: MME (2008) in BNDES and CGEE (2008)	54
Figure 2.4	Oil prices and main events, from 1970-2014. Source: US DOE	55
Figure 2.5	(a) Minister Shigeaki Ueki fuelling ethanol in a car in Brazil;(b) President Ernesto Geisel (first on right) receiving entrepreneurs to discuss the PROALCOOL. Source: CORTEZ (2016)	56
Figure 2.6	Evolution of commercial sugarcane varieties from 1974-2010 in Brazil. Source: CORTEZ (2016).	57
Figure 2.7	Main phases of PROALCOOL 1972-2015. Source: CORTEZ (2016)	60
Figure 2.8	Green sugarcane mechanized harvesting in Brazil. Source: Arthur Saraiva, site EMBRAPA	62
Figure 2.9	Sugarcane ethanol learning curve, price of ethanol according to the accumulated ethanol production volume. Obs: green-ethanol BR, yellow-gasoline BR, orange-gasoline Rotterdam. Source: GOLDEMBERG et al. (2004)	64
Figure 2.1	0 Authorized nominal capacity and biodiesel consumption in 2019. Source: EPE (2020)	67
Figure 2.1	1 Evolution of ethanol (anhydrous and hydrous) and biodiesel in Brazil. Source: DATAGRO and ANP, from LEAL (2022)	68
Figure 3.1	Evolution of gasoline (E25) and hydrous ethanol (E100) consumption in Brazil depending to the engine type. Source: ANFAVEA, cited by OLIVÉRIO (2008)	74
Figure 3.2	Present and future estimations of ethanol production and imports from Brazil. Source: EPE based on EPE (2017)	76
Figure 3.3	Brazilian exports and imports of ethanol from 2008 to 2019. Source: EPE (2020) from MME (2020)	76
Figure 3.4	Productivity, harvested cane, and destination to ethanol and sugar. Source: EPE (2022)	77
Figure 3.5	Projection of Brazilian production of sugar until 2031. Source: EPE (2020)	78

-	Лар of sugarcane distribution in Brazil. Source: NIPE-Unicamp; BGE; CTC (2017)	79
-	thanol mills entering in operation 2006-2030 (projected). Source: PE (2022) based on MAPA, UNICA, and EPE projection	81
Figure 3.8 C	Otto cycle demand and share of different fuels. Source: EPE (2020)	81
-	werage price of fuel ethanol in relation with gasoline C (E27.5). ource: EPE (2020) from ANP	82
Figure 3.10	Sugarcane composition and its energy value. Source: DEDINI (2016)	82
Figure 3.11	Electricity contracted in energy auctions by free market -2021-2025. Source: EPE (2022)	83
Figure 3.12	Potential for electricity exports from sugarcane bagasse to the grid. Source: EPE (2022)	83
Figure 3.13	Self-consumption and electricity sold by sugar & ethanol mills in Brazil. Source: EPE (2020)	84
Figure 3.14	Ethanol and sugar producing mills and logistics infrastructure (pipelines) in Brazil. Source: EPE (2022) based on MAPA and LOGUM	85
Figure 3.15	Integrated logistics system for ethanol transportation using pipelines in São Paulo and Rio. Source: adapted from LOGUM/EPE (2020)	86
Figure 3.16	Overall corn production in Brazil. Source: CONAB / elaborated by Scot Consultoria	87
Figure 3.17	Corn ethanol production in Brazil. Source: EPE (2020) from UNICA	87
Figure 3.18	Share of raw materials for biodiesel production in 2019 in Brazil. Source: EPE (2020) from ANP (2020)	89
Figure 3.19	Biodiesel expected demand by Brazil. Source: EPE (2022)	90
Figure 3.20	Localization of biodiesel plants and its logistics routes. Source: EPE (2022)	91
Figure 3.21	Evolution of biodiesel regulatory framework in Brazil. Source: EPE (2020)	92
Figure 3.22	Average prices for biodiesel and diesel in Brazil, without taxes ICMS), from 2016 to 2019. Source: EPE (2020)	92

Figure 3.23	GHG emissions in Brazil from 1990 to 2020 (GtCO ₂ e). Source: SEEG (2021)	97
Figure 3.24	Sugarcane seedlings been grown in greenhouses as part of new planting systems. Source: image provided by Andrés da Silva (EACEA)	99
-	Seventeen selected areas for potential production of sugarcane in Brazil. Source: LEITE (2009)	108
(Potential for sugarcane production in Brazil, considering soils and climates, (a) non-irrigated, and (b) with survival irrigation. Source: LEITE (2009)	109
-	GranBio G2 Ethanol plant in São Miguel dos Campos, AL. Source: GranBio	110
Figure 4.4 I	RAÍZEN G2 ethanol plant in Piracicaba, SP. Source: G1 (2015)	111
0	Integration of a thermochemical process with an existing sugar mill. Source: KIT and IPT (2022)	114
Figure 4.6 I	Land occupation in Brazil. Source: EMBRAPA	116
	Evolution of GHG emissions by the Brazilian beef cattle, in Gtons of CO _{2equivalent} (1990-2020). Source: SEEG/Observatório do Clima (2022)	117
•	Average price of E100 and gasoline-ethanol price parity for different states in Brazil – 2001 to 2009. Source: Souza (2010) using ANP data	118
Figure 4.9	Average yield of Corn in Brazil in 2011, 1 st harvest. Source: EMBRAPA	119
Figure 4.10	Localization and production capacity of few corns' ethanol plants in Mato Grosso and Goiás	121
Figure 4.11	Schematic view of LUC and iLUC processes. Source: by the authors	123
-	Energetic consumption vs total GHG emissions from well to wheel. Source: AEA (2017)	139
-	GHG emissions (gCO2e/km) for electric passenger cars used in different countries compared with hybrid+ethanol in Brazil, and ethanol in Brazil. Source: RAÍZEN (2022)	140
- 1	Raw materials and their relative position according to costs and technical efforts to be converted into sustainable aviation biofuel. Source: CORTEZ (2014a)	147

Figure 5.4	Identified pathways to produce sustainable jet biofuel in Brazil. Source: BOEING/EMBRAER/FAPESP (2013)	148
Figure 5.5	GHG emissions in the production of various plastics of fossil and biomass origin. Source: AKIYAMA et al. (2003)	154
Figure 6.1	One of the first ethanol fuelled vehicles in Brazil, a Ford automobile, specially prepared at the Estação Experimental de Combustíveis e Minérios (today Instituto Nacional de Tecnologia-INT). Source:	
	INT (2022)	162