SUPPLY AND DEMAND OF BIOMASS-BASED ENERGY IN BRAZIL: ESTIMATES USING TIME SERIES ANALYSIS AND CURRENT POTENTIAL

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Overview

In this work, we developed estimates of the supply and demand of biomass-based energy in Brazil. This type of energy is receiving increasing attention due to its benefits in terms of sustainability and trade balance. We applied time series analysis to forecast demand based on historical data and vector autoregressive models. As regressors, we included total energy consumption, electricity prices, air temperature, population, local stock market size, industrial growth, FDI and GDP. The energy potential was estimated based on agricultural, livestock, urban solid waste and forestry production. The projections indicate that the demand in 2032 can reach 187 million tons of oil equivalent, which is around 41% of the 457 million tons of national energy potential based on the production of 2022. The results show a significant gap between the projected use and the potential supply of this type of energy in the country. A national energy planning aimed at exploring this gap, while considering its effects with respect to inputs, costs and other uses, may lead to a higher share of alternative energy sources, better diversification and improved efficiency.

KEYWORDS: Biomass, Energy Potential, Bioenergy, Alternative Sources, Autoregressive Models.

1. INTRODUCTION

Global energy demand has grown by around 69% from 1990 to 2020, in line with a population growth of 48% in the same period, especially in emerging countries (Zeb et al., 2017). Most of this energy is used for electricity generation and transportation. Despite the increasing awareness with respect to the harmful effects of the excessive use of fossil fuels over the last decades, the rupture of global chains with the Covid-19 pandemic and the war in Ukraine have, at least temporarily, shifted the concern to avoiding supply deficits (IEA, 2022). Nevertheless, countries participating in COP26 in 2021, including Brazil, agreed to minimize the use of coal and other fossil fuels to reduce carbon dioxide emissions and their effects on the climate change, as well as human and animal health and well-being (Wang et al., 2022). This study seeks to contribute to this process by developing projections of supply and demand for energy from biomass, a resource that still accounts for only 10% of the global energy production, but which has several advantages in terms of availability, cost, inclusion and sustainability.

Biomass is a renewable energy source derived from four basic sources: woody plants (timber), non-woody plants (saccharides, cellulose, starch and aquatic), organic waste (agricultural, industrial and urban) and biofluids (vegetable oils) (Field et al., 2008). In Brazil, sugarcane bagasse is the most widely used biomass resource for energy generation, given the importance of the sugar and alcohol sector and high levels of waste generation. Palm oil, wood chips, food waste and even animal manure are also used (Hofsetz & Silva, 2012). The main biomass conversion processes are direct combustion, in ovens and stoves; gasification, using hot steam and air without causing combustion; pyrolysis or carbonization; transesterification, converting vegetable oils into glycerin or biodiesel; anaerobic digestion, decomposing through the action of bacteria (generating biogas and, after purification, biomethane, equivalent to natural gas); and fermentation, in which yeasts convert sugars into alcohol (Hu et al., 2020). Biomass-based generation systems can also include cogeneration processes, in which the heat generated in the production of electricity is incorporated into the production process in the form of steam, saving fuel and increasing the efficiency of the system.

One of the main advantages of biomass energy generation is its availability. All the time, we generate organic waste in an intense and distributed way. Almost all extraction, production, transportation and consumption units produce waste that can be converted into heat and electricity. In terms of sustainability, the release of carbon into the atmosphere from the use of fuels from plant biomass is limited to what was absorbed by the plants during their life cycle (Winchester & Reilly, 2015). In addition, since the waste generation is decentralized, transportation costs from generation units to consumption units tend to be lower. Biomass also does not require the high extraction costs typical of the oil and gas industry and can represent a supplementary income for existing industrial units. Finally, the use of solid waste for energy generation reduces the volume deposited in landfills.

On the other hand, the use of biomass energy also has disadvantages (Vassilev et al., 2015). Despite significant research and technological innovations, the energy efficiency of biofuels is still limited when compared to fossil fuels. Furthermore, the use of biomass from human or animal waste leads to an increase in methane emissions, which are also harmful to the environment. Pollution from burning wood and other materials can be as harmful as that from the use of coal and similar resources. The biomass-based energy generation should be combined with the development of solutions to overcome these disadvantages, as well as avoiding increasing levels of deforestation for the use of wood.

A key challenge for energy supply and demand planning is the development of projections with adequate degrees of reliability (Moreira, 2006;

Senocak & Goren, 2022). Regarding biomass-based energy, this issue is even more critical due to the fragmentation, informality and less regulation (Mafakheri & Nasiri, 2014). Aiming at overcoming this problem, in this study we developed both supply and demand projections for biomass energy, year by year, in Brazil. Our approach encompasses the definition of supply and demand determinants, data collection in previous literature, and the use of autoregressive vector models with a bootstrapping technique to overcome sample size problems.

The estimated supply and demand forecasts are useful for planning and operating processes of producers, industries, consumers and regulators. With greater predictability, there is a tendency for reduction in transaction costs and risk premiums, as well as in the uncertainties of projects aimed at increasing supply and projects that will demand this supply (Rosillo-Calle, 2016). Thus, despite its limitations and room for improvements, this work contributes to the development and improvement of national energy plans, capturing the benefits of biomass-based supply.

We selected the main crops and sources of waste that are inputs for the generation of biomass energy, using production and generation data from 2022. We collected consumption and specific energy parameters from various sources and estimated a potential supply of biomass-based energy of 457 million tons of oil equivalent (toe). Regarding consumption, our projections are based on the time series published by the Energy Research Company (EPE), a public company linked to the Brazilian Ministry of Mines and Energy that develops studies and research aimed at supporting the planning of the energy sector. We also used series of typical macroeconomic determinants of energy consumption. Using data from 2000 to 2021, we developed autoregressive vectors that indicate that consumption may reach 187 million toe in 2032, 41% of the current estimated supply potential.

In the next section, we describe the data, parameters, and methods used for the research goals. Finally, we analyze the results and make final comments, presenting limitations of our study and recommendations for future work.

2. METHODS

First, we estimated biomass energy consumption in Brazil from 2022 to 2032, applying historical data from 2000 to 2021 to VAR (vector autoregressive) models. Historical consumption data of total energy and of biomass-based energy were extracted from a periodic report released by EPE. Biomass-based energy corresponds to the one from sugarcane bagasse, firewood, black liquor, biogas and other recoveries, in tons of oil equivalent (toe). Total energy comprises electricity, ethanol, fossil fuels, solar and other renewables, also in toe. We also collected variables that Samuel et al. (2013) identified as determinants of energy consumption: total country population, real gross domestic product growth and industrial growth, released by the IBGE (Brazilian Institute of Geography and Statistics); market cap of listed domestic companies and foreign direct investment, released by the World Bank (WB); residential electricity prices, available at the CEIC (Global Economic Data, Indicators, Charts & Forecasts) website; and air temperature, measured by the INMET (National Institute of Meteorology). The variables and corresponding sources are described in Table 1.

Table 1 - Descriptive Statistics

Variable (unit)	2000	2021	Mean	Min	Max	SD	Source
Biomass-based energy consumption (million toe)	34,27	63,75	53,40	34,27	66,11	8,85	EPE
Resid. electricity price (USD per BOE)	192,31	277,64	308,95	157,27	425,68	81,57	CEIC
Total energy consumption (million toe)	156,52	248,55	212,80	156,52	248,55	33,04	EPE
Country population (million inhabitants)	173,77	213,32	194,90	173,77	213,32	12,10	IBGE
Air temperature (degrees Celsius)	23,28	24,65	24,13	23,28	24,84	0,43	INMET
Real gross domestic product (GDP) growth (%)	4,39	4,80	2,26	-3,55	7,53	3,01	IBGE
Market cap of listed local companies (% of GDP)	34,50	49,50	50,07	24,87	98,04	17,88	WB
Industrial growth (%)	6,50	3,90	0,51	-8,30	10,50	5,04	IBGE
Foreign direct investment (% of GDP)	5,03	2,80	3,22	1,73	5,03	0,88	WB

Note: BOE stands for barrels of oil equivalent.

We then verified whether stationarity requirements are met applying augmented Dickey-Fuller tests. We performed log transformation and took first and second differences of the series until they become stationary, resulting in the variables presented in Table 2. Originally, we considered per capita real GDP, capital stock, domestic credit to the private sector and the number of listed domestic companies, but they did not become stationary after the transformations.

Table 2 - Results of the Augmented Dickey-Fuller Tests

Variable (unit)	Statistic	P-value
Second difference of the log of biomass-based energy consumption	-4,14	0.02
Log of residential electricity price	-3,74	0.04
Second difference of the log of total energy consumption	-4,47	Less than 0.01
Second difference of the log of country population	-3,28	0.09
Second difference of the log of air temperature	-6,02	Less than 0.01
Second difference of the log of real GDP growth	-6,04	Less than 0.01
Second difference of the log of market cap of listed local companies	-4,97	Less than 0.01
Second difference of industrial growth	-4,77	Less than 0.01
Second difference of foreign direct investment	-5,48	Less than 0.01

Note: The alternative hypothesis of the Augmented Dickey-Fuller Test is stationarity.

After that, we applied autoregressive models of order 3, since it showed better results with respect to the Akaike information criterion (AIC). Due to the small sample size, instead of a model with all the variables, we combined the biomass-based energy and the eight other regressors in 28 models with three variables and stored the forecasted log of the second difference of biomass-based energy consumption. Finally, we calculated predicted biomass-based energy consumption based on these forecasts. Model outcomes resulted in a biomass-based consumption in 2032 ranging from 39 to 187 million toe.

The second part of our analysis comprised the estimation of the potential for production of biomass-based energy in Brazil. Whenever we found more than one parameter value in the literature, we chose the lower one to have conservative estimations. Firstly, we estimated the potential for energy generation based on biomass from crops in Brazil. We extracted data of the Municipal Agricultural Production (PAM) in 2022, released by IBGE (Brazilian Institute of Geography and Statistics). We considered all products with national production above one million tons in 2022, both permanent and temporary crops. We estimated the energy in toe based on the methodology presented by Gonzalez-Salazar et al. (2014), which is basically the production of the agricultural product multiplied by waste to product ratio, adjusted by the moisture content, and finally multiplied by the lower calorific value.

Among the 27 products (that total 1.1 billion tons in Brazil in 2022), we did not find the parameters only for papaya (1.1 million tons) and watermelon (1.9 million tons). The parameters and resulting potential of energy production for permanent and temporary crops are presents in Tables 3 and 4, as well as main references used to obtain these parameters.

Table 3 - Inputs and Outputs for Major Permanent Crops

Crop	Outcome (million tons)	Outcome (billion BRL)	By-product	By-product to product ratio	Moisture content (min)	Lower heating value (kJ/kg, min)	Potential energy production (ktoe)
Orange	16,93	14,37	Pomace bran	1.59[1]	0.40[1]	25,240[9]	9.736
Banana	6,85	11,92	Pseudo-stem, stalks	4.12[2]	0.92[6]	8,346[6]	450
Coffee	3,17	51,81	Peel and residues	0.28[6]	0.32[6]	17,186[6]	249
Palm oil	2,95	1,23	General waste	0.81[3]	0.10[7]	18,400[7]	953
Coconut	1,83	1,60	General waste	0.60[2]	0.10[7]	18,400[7]	436
Açaí	1,70	6,17	Acai seeds	0.80[4]	0.09[4]	21,700[4]	642
Lemon	1,63	2,08	CPW[10] and peel	1.59[1]	0.40[1]	18,000[1]	669
Mango	1,55	2,07	Waste	0.39[2]	0.08[8]	16,130[8]	215
Grape	1,45	4,54	Stalks	0.10[2]	0.50[1]	20,038	35
Tangerine	1,09	1,60	CPW[10] and peel	1.59[1]	0.40[1]	18,000[1]	446
Apple	1,05	1,98	Pruning residues	0.13[5]	0.38[5]	17,677[5]	36

Note: 1: Algieri et al. (2019). 2: Silva et al. (2019). 3: Elauria et al. (2005). 4: Santos et al. (2020). 5: Ekinci (2011). 6: Gonzalez-Salazar et al. (2014). 7: Yerima & Grema (2018). 8: Tahir et al. (2021). 9: Gravalos et al. (2016). 10: Citrus peel waste. 11: Thousand tons of oil equivalent.

Table 4 - Inputs and Outputs for Major Temporary Crops

Crop	Outcome (million tons)	Outcome (billion BRL)	By-product	By-product to product ratio	Moisture content (min)	Lower heating value (kJ/kg, min)	Potential energy production (ktoe)
Sugarcane	724,43	93,48	Vinasse, bagasse[1]	1.72[2]	0.36[5]	15,561[5]	297.256
Soybeans	120,70	345,42	Straw and others	1.40[2]	0.15[6]	14,900[6]	51.117
Corn	109,42	137,74	Straw, cob, others	1.42[2]	0.14[5]	14,546[5]	46.553
Cassava	17,65	15,30	Residues and vines	0.69[2]	0.62[7]	16,300[7]	1.775
Rice	10,78	15,53	Straw and husks	1.49[2]	0.66[5]	13,100[5]	1.710
Wheat	10,34	15,70	Straw and others	1.40[2]	0.15[6]	13,900[6]	4.086
Cotton	6,42	33,13	Vines, husks, cores	2.95[2]	0.07[5]	14,790[5]	6.224
Potatoes	3,89	6,73	Cull potatoes	0.10[3]	0.81[3]	4,302[3]	8
Tomatoes	3,81	8,66	Pulp, skins, seeds	0.01[4]	0.10[4]	19,500[4]	14
Sorghum	2,92	2,91	General residues	0.50[2]	0.50[8]	15,899[8]	278
Beans	2,84	12,37	Straw and others	3.67[2]	0.05[6]	14,700[6]	3.479
Onions	1,66	4,11	Cull onions	0.05[3]	0.90[3]	4,024[3]	1
Pineapple	1,56	2,76	Bran	0.60[2]	0.05[9]	17,590[9]	372
Oats	1,30	1,48	Biomass of cultivars	See note 11		16,000[10]	74

Note: 1: Filter cake, straw and stalks also included. 2: Silva et al. (2019). 3: Frear et al. (2005). 4: Khiari et al. (2019). 5: Gonzalez-Salazar et al. (2014). 6: Avcıoğlu et al. (2019). 7: Veiga et al. (2016). 8: May et al. (2013). 9: Santos et al. (2018). 10: Pinto et al. (2021). 11: Energy potential calculated based on the area intended for harvesting of 554 thousand hectares. 12: Thousand tons of oil equivalent.

Regarding livestock biomass, we obtained data from the Municipal Agricultural Production (PPM) in 2022, also from IBGE. We considered cattle, swine, poultry and equine. We estimated the energy potential of the waste based on the methodology also presented by Gonzalez-Salazar et al. (2014), which considered as reference the amount of biogas produced from each animal's manure through a biodigestion process. The formula relates the number of animals to the production of manure per animal, the yield of biogas per manure and a lower calorific value of 17 MJ per m3. We present parameters and resulting potential of energy production for livestock in Table 5.

Table 5 - Inputs and Outputs for Major Types of Livestock

Type	Million heads (2022)	Ton of residues to heads ratio[1]	Volume in m³ per ton of residue[1]	Potential energy production (ktoe)
Cattle	234,4	4,11	23	8.995
Swine	44,4	0,66	40	478
Poultry	1859,5	0,02	55	872
Horses	5,8	7,45	32	561

Note: 1: Parameters collected from Gonzalez-Salazar et al. (2014), which is based on a literature review.

We estimated the energy potential from forest biomass using the survey carried out by IBGE on the production of plant extraction and forestry in Brazil. The production volume of charcoal and cellulose (which can be used for bleach production) in 2022 was 7.1 million and 25.0 million tons, respectively. We also considered the 52.8 million and 158.3 million cubic meters of firewood and round wood, as well. Those volumes were converted into weight using an average density of 0.33 ton/cubic meter. Hence, we considered a by-product to product ratio of 0.3 (1.4 for cellulose) and a lower calorific value of 16.7 kJ/kg (12.0 kJ/kg for cellulose). The values of those parameters were obtained and presented by Gonzalez-Salazar et al. (2014) and Liebel (2014), based on a literature review. The resulting potential energy was 854 thousand and 10,031 thousand toe (ktoe) for charcoal and cellulose, respectively, and 2,088 thousand and 6,263 ktoe for firewood and round wood, respectively.

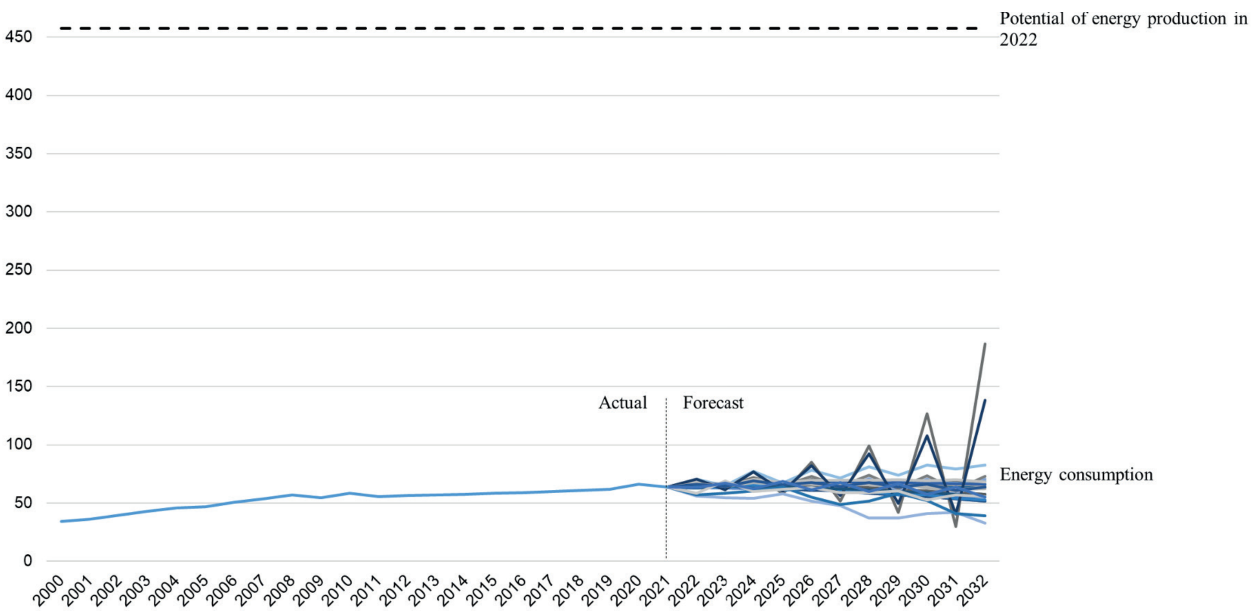
Finally, with respect to the urban solid waste, we considered the estimate made by IPEA (Brazilian Institute of Applied Economic Research) that approximately 160 thousand tons of waste of this type are generated per day in Brazil, discounted by an ideal recycling rate of 60%. We converted this weight of 35.0 million tons into a landfill volume of 2.4 billion cubic meters, using a ratio of 67.9 cubic meter per ton, and then into energy potential using a lower calorific values 10.2 MJ per cubic meter, as cited by Gonzalez-Salazar et al. (2014). The resulting potential energy was 580 ktoe.

3. RESULTS

According to the historical data, total biomass consumption showed a relevant increase in its share of the energy matrix, equivalent to 86.5%, between 2000 and 2022 (2.9% per year), going from 34 to 64 million toe. This energy comes mainly from the use of sugarcane bagasse in cogeneration systems. In line with this growth rate, our model predictions resulted in an average forecast of 68 million toe in 2032 (ranging from 33 to 187 million), an increase of 6.2% compared to 2022.

With respect to the annual energy potential, our estimate was 457 million toe, 14 million based on biomass from permanent crops, especially orange, 412 million based on biomass from temporary crops, particularly sugar cane, soybeans and corn, 11 million from livestock farming, 19 million from plant extraction and forestry, and 579 thousand toe from the use of urban solid waste. Actual biomass energy consumption in Brazil in 2022 represents 14% of this consolidated estimate of potential generation. Average projected biomass energy consumption in Brazil in 2032 represents 15% of this same estimate, ranging from 7% to 41%. Figure 1 compares actual and projected forecasts of biomass-based energy consumption, as well as the estimated production potential with data from 2022.

Figure 1 – Biomass-based energy in Brazil (million toe)



4. CONCLUSIONS

Our analysis shows that there is still a considerable gap between Brazil's biomass-based energy consumption and its production capacity based on the generation of waste and co-products in agriculture, livestock, forestry and urban activities. Considering the advantages of this type of energy in terms of carbon neutrality, energy security with local production chains, and socioeconomic development, this scenario favors the adoption of public policies to stimulate an increase in the production, through tax incentives and special lines of financing for the acquisition of machinery and the development of both waste and co-product supply chain and the flow of the produced energy. Some studies about these topics show interesting analyses (Cansino et al., 2010; Zhao et al., 2016, Mingyuan, 2005; Khennas, 2000; Tan et al., 2019)

Moreover, the promotion of research and innovation initiatives to improve the efficiency of waste-to-energy conversion processes contributes to this goal, as well as the modernization of the legal and regulatory framework related to the use of waste and to energy trade (Qazi et al., 2018; Banja et al., 2019). Such policies should include an evaluation of the effects of any stimulus in terms of the inputs needed to intensify the production, as well as its impact on other supply chains.

It is important to highlight that our consumption projection method is based on the historical growth and a limited number of determinants, and that actual demand could be even greater due to the contribution of supply and other structural shocks, such as new public policies to encourage the production and use of this type of energy, or to reduce the use of fossil fuels. Furthermore, our estimates of potential supply are based on data about waste generation of 2022, which means that it may also present a growth projection that can be addressed in future work. Intra-year forecasts, supply determinants, capital expenditures and present value estimates, and the cross-effects between biomass types are also promising venues for future research.

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