MEASURING GROSS EMPLOYMENT GENERATION POSSIBILITIES IN THE BIOGAS VALUE CHAIN IN SOUTHERN BRAZIL

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Abstract

Biogas is generated from substrates derived from agriculture and cattle, agroindustry (slaughterhouses, flour, and sugar mills), urban solid waste, and sewerage treatment. This study measures the current and potential production and gross employment in the biogas value chain in three southern states in Brazil (Paraná, Santa Catarina, and Rio Grande do Sul). We offer two contributions: first, an input-output methodology to focus on the problem of disparate or nonexistent sectoral information, both in monetary and physical units; second, the quantitative results of output and gross job creation derived from shocks at the regional level. We calibrate input-output matrices of the three states with compatibilized sector entries, opening new ones for those not included in official statistics (derived from specific surveys). Once the baseline has been established, we consider three scenarios: demand-pull that achieves full capacity utilization, supply push that addresses new investments in the sector assuming guaranteed demand, and full utilization of substrates supply for biogas production. Employment multipliers are in line with literature on comparative activities found elsewhere in the world. Our findings support the hypothesis of the relatively high labor intensity in the biogas industry.

Keywords: biogas, Brazil, input-output, employment
JEL classification: Q42, R15

1. Introduction

Climate change is one of the most important global concerns nowadays, and one of the key factors in understanding it is greenhouse gas (GHG) emissions. Currently, GHG emissions have reached unsustainable levels, prompting the adoption of environmental policies by several countries, and more importantly, collective action at the global level. This has generated concern and proactive interest in controlling global warming and minimizing the costs of climate change on humanity's welfare. The international community, within the framework of the United Nations, has initiated negotiations between countries (United Nations Framework Convention on Climate Change - UNFCCC), whose objectives are aligned with the international commitments of the Paris Agreement on Climate Change (an international initiative to decarbonize and hence cap global warming) and the United Nations Sustainable Development Goals (SDG) for 2030. Fossil fuels are responsible for a great share of GHG emissions, and part of the solution is its progressive replacement with renewable energies. Considering that globally 73% of GHG emissions come from the energy sector and 27% from the rest of the productive sectors (IPCC, 2023), it is essential to promote the increased use of renewable sources to reduce emissions (IPCC, 2015). The problem has several facets, one being the replacement of fossil fuels with "greener" energy generated from biomass. Biomass is defined as "the biodegradable fraction of products, waste, and residues from biological origin from agriculture, including vegetal and animal substances, forestry, and related industries including fisheries and aquaculture, as well as the biodegradable fraction of waste, including industrial and municipal waste of biological origin" (European Biogas Association, 2020).

According to the targets in the Brazilian National Determined Contribution to Paris Agreement, the country aims to reach a 45 percent share of renewable energies in its energy matrix by 2030 (in addition to the current relatively high share of hydroelectrical energy sources in Brazil) (Fundação Getúlio Vargas, 2019).

Among the possibilities of applying biomass to produce fuels is biogas generated from anaerobic decomposition from several organic matters. Biogas and biomethane have the potential to support all aspects of the SDGs, which chart a path entirely consistent with the Paris Agreement and meet objectives related to universal energy access and cleaner air. Moreover, from the supply side, the tropical climatological characteristics of the country provide comparative advantages for biogas production in Brazil (Mariani, 2018). The three major energy conversion technology paths of biomass are 1) physical-chemical conversion (compression and crushing of vegetal matters to extract oil, later chemically transformed, yielding biofuels); 2) Thermo-chemical conversion (energy chemically stored in solid waste or timber that is converted into heat using combustion via different processes); 3) biochemical conversion (biomass transformation from biological and chemical processes, including anaerobic digestion, fermentation/distillation and hydrolysis). Anaerobic digestion consists of the biological degradation of organic material –sewage sludge, animal and vegetal by-products, household biowaste, and primary or secondary crops–, resulting from the action of several microorganisms in the absence of oxygen. The 'bio' aspect of biogas refers to its biological production process and renewable (biomass) origin, in opposition to 'natural gas' which is of fossil origin (European Biogas Association, 2020).

The arguments in favor of biogas and biomethane, which make it possible to deal with the increasing amount of organic waste produced by modern societies, lie at the intersection of fundamental challenges to meet SDGs: 1) Reducing global greenhouse gas emissions, 2) Increasing economic activity, and 3) fostering employment. The latter is of particular interest, since conventional fossil energies are industries comparatively intensive in capital, while most renewable energies, and biogas in particular, are comparatively intensive in labor. Biomass encompasses several forms of substrates, which are substances or surfaces that an organism grows and/or lives on and is supported by (European Biogas Association, 2020). Biogas can be a valuable local source of power and heat, as well as a clean cooking fuel to displace reliance on the traditional use of solid biomass in many developing countries. There are also potential co-benefits in terms of agricultural productivity (because of using the residual "digestate" from biodigesters as a fertilizer) and reducing deforestation.

Brazil has great potential for biogas production (82.6 billion m3 per year according to ABiogás, of which the current production is around 2.8 billion or 3.4 percent of the potential) due to its availability and the diversity of substrates in an extended geography. According to UNIDO (2020 b), three states in the south (stretching over 564 thousand square kilometers, or 6.6 percent of the country's size), produced only 5 percent of their biogas potential production. UNIDO (2023) measures the current and potential production and employment in the biogas value chain in three southern states in Brazil – Paraná, Santa Catarina, and Rio Grande do Sul (hereafter PR, SC, and RS), known together as the South Region. Those states have a combined population of 30 million inhabitants and recorded a GDP of US$ 323 billion in 2019, being the fourth, fifth, and sixth biggest states in terms of Brazilian GDP after Sao Paulo, Rio de Janeiro, and Minas Gerais.

Reliable statistics are crucial to diagnose the state of an economy and simulate the effects of policy interventions. The answer to the question of how much value added (or gross production value GPV) and/or employment one sector of an economy generates is usually determined using public statistics, routinely compiled, and processed by national statistical bodies. In developing countries, however, the information on output and jobs is normally limited and is not available for all periods, all meaningful sector disaggregation, or all regions. Difficulties escalate when determining production and employment in such a very specific sector as biogas, in highly specific regions, and on a very specific date. If they do exist, they have probably been updated, and if the economic structure of the jurisdictions differs, the sectors considered in each jurisdiction are expected to vary. This is the case in Brazil's South Region.

We make two contributions. First, we deal with a method to study the problems of 1) measuring production and gross job creation, addressing the compilation of scant data and generating systematic information; 2) opening entries and periods of measurement that lack detail and scope; 3) disaggregating sectors that are not currently considered in the statistics because they are new sectors, or small ones, or have not been studied in depth, and 4) putting together coherent monetary (production) and physical units (employment and emissions), and thus connecting production increases along with gross job creation. Second, we estimate direct, indirect, and induced nexuses between production and employment to understand the gross jobs generated in the activity itself, plus all the spillovers the sector generates in the rest of the economy (to providers of inputs or services; from buyers of production).

In doing so, we calibrate an Input-Output Model for each state with the biogas sectors now included as separate activities to adequately measure production and employment. In addition, we produce simulations of interest for policymakers, focusing on production increase, and job gains of shifting partially the energy matrix from fossil to biogas production. The scenarios we propose improve the capacity utilization (from an initially important idle capacity), another that promotes expanding capacity (on the assumption of demand that fully absorbs new supply), and a third one, just to evaluate its full potential, consisting of a complete use of all available biomass in the South of Brazil to produce biogas. Each scenario can be impulse by a different policy set.

After this Introduction, Section 2 presents a literature review. Section 3 deals with the methodology. Section 4 examines the data, and introduces primary information, secondary data, and the baseline. Section 5 presents and discusses the scenario design and results and offers some sensitivity analyses. Section 6 concludes.

2. Contextual settings

2.1. Concept and technologies.

The Circularity GAP Report estimates that roughly 90 percent of the resources are not reinserted in economic activities worldwide. Biomass energies are forms of reducing the circularity gap, promoting natural capital preservation, and reducing emissions (Fundação Getúlio Vargas, 2019). One of the byproducts of biomass is biogas. Biogas is mainly composed of methane (50-75%), carbon dioxide (25-50%), steam, and other gases in low concentrations such as hydrogen sulfide, hydrogen, and nitrogen.

Biogas production helps prevent methane emissions in the atmosphere from agricultural by-products that otherwise are left to rot, such as manure. As such, biogas can play a key role in mitigating GHG emissions in agriculture, especially methane emissions – the second most important GHG after CO2-. Moreover, biogas can provide non-intermittent energy all year long, turning organic waste and residues into valuable products, allowing for nutrient recycling and energy production locally. Biogas can be used as biofuels, to generate electricity, for heating or air conditioning, and as a substitute for natural gas, steam, and bioproducts, being capable of serving a broad range of industries (ANP, 2015a; ANP, 2017).

The production process is as follows: 1) the pre-treatment of substrates; 2) anaerobic digestion in a biodigester; 3) treatment, storage, and transport of biogas, and storage, treatment, and use of digestate; 4) the use of biogas in electricity or heat generation; and production, storage, and transport of biomethane by raising the content of methane from 60 percent in biogas to 90 percent in biomethane; 5) Use of the biogas in the natural gas network, as vehicle fuel, or for industrial production (Mariani, 2019).

Anaerobic digestion can yield biogas or digestate, and biogas can also be "upgraded". Digestate used as organic fertilizer makes it possible to reuse nutrients and it substitutes mineral fertilizers of fossil origin. Upgrading is the "*process of separating unwanted components in biogas (such as carbon dioxide) to increase the total methane share and meet natural gas standards.*" (European Biogas Association, 2020). When upgraded, biomethane (also known as renewable natural gas) is indistinguishable from natural gas and can be transported and used in the same way. Biomethane can be injected into the natural gas network or used industrially. Biomethane can deliver the energy system benefits of natural gas while being carbon neutral. Currently around 3.5 Mtoe of biomethane are produced worldwide. Most of the production lies in European and North American markets, with some countries such as Denmark and Sweden boasting more than 10% shares of biogas/biomethane in total gas sales. Countries outside Europe and North America are catching up quickly, at disparate speeds, with the number of upgrading facilities in Brazil, China, and India tripling since 2015 (IEA, 2018).

2.2. Accounting for the biogas impact on the economy and employment

The Input-Output Analysis and Computable General Equilibrium (CGE) models are the most common tools to measure a sector’s expansion impact with widespread diffusion to solve several problems, such as recalculating the sectoral structure of production, analyzing changes in employment, accounting for emission reduction, assessing the impact on the international markets, evaluating taxes and subsidy impacts, etcetera, as Brinkman et al., (2019), Garrett-Peltier (2017), Lehr et al., (2008), Pollin and Garret-Peltier (2009), Malik et al. (2014), Lester et al. (2015), and Alarcon and Ernst (2017) assert, among others.

The Input-Output analysis makes it possible to show how the parts of a system are affected by changes in other related parts. The measurement of socioeconomic impacts in each economy helps assess clearly and in detail all the social costs and benefits of a certain sector’s expansion or reduction (Brinkman et al., 2019). For instance, Romero et al. (2023 a) contribute to understanding the effects of the increment of recycling activities on production, employment, and the environment in a developing country with a large informal labor sector, by using an enhanced input-output matrix or waste input-output matrix (WIO), within a hybrid (including monetary and physical transactions) model accounting for the recycling sectors interlinking with the rest of the economy and final consumption. In the same vein, Romero et al. (2023 b) address the problem of estimating renewable energy’s impact on regional economies of developing countries, owing both to the lack of disaggregated data on these renewable energy sources at the subnational level and a method to address its share in the energy matrix.

Job creation in the renewable energy sectors is related to the control of environmental impact and sustainable projects (Lehr et al., 2008; Breitschopf et al., 2011; Garret-Peltier, 2017). Nevertheless, its statistics determination is difficult, as Rojo et al. (2020) and Stoevska and Hunter (2013) state.

The monetary values of Input-Output tables could not effectively address the allocation of jobs because the monetary values per physical unit can differ significantly in several supply chains: in fact, biogas can be produced with several substrates, on different scales, and with different intensities of labor.

3. Biogas in the South of Brazil

Brazil has no integrated structure in its biogas industry but rather it encompasses heterogeneous initiatives coming from different sectors (Fundação Getúlio Vargas, 2019). Moreover, in this country, the prevailing technology is predominately low implantation and maintenance costs, more oriented by environmental concerns than by energy production. The biogas sources come mainly from substrates of agriculture and cattle raising and their processing industries (dairy, slaughterhouses, beer brewing, flour, and sugar mills, etc.), organic solid waste, and sewerage treatment.

In 2021 CiBiogás (2021) estimated that 675 biogas plants were built in Brazil (638 were active), and the number of plants was growing swiftly (20 percent annual rates since 2015). Most plants are small (less than 1 million Nm3 capacity for biogas production, being Nm3 the quantity of gas contained in a cubic meter under normalized pressure and temperature), and roughly 80 percent of these plants produce 8 percent of all the biogas that the country provides. On the other hand, 6 percent of big plants produce 80 percent of biogas. Small plants are mainly rural cattle exploitations of porcine, bovine, and poultry, whose production of biogas is mostly devoted to electricity generation for self-consumption. Biogas can also produce electricity to be sold to the power network or produce biomethane as a substitute for natural gas for vehicles. Biogas production is concentrated in the southeast, northeast, and southern regions (CiBiogás, 2021).

Brazil raises 1 billion poultry, more than 200 million bovines, and 38 million porcine, with combined dejections of 1 million tons per day. In 2018, 30 million bovines and 42 million were slaughtered, producing several thousand tons of residues in the process. The country is the fourth dairy world producer and on average every kilo of the final product generates 3 to 5 liters of effluent. Brazil is also the third greatest producer of beer worldwide, after China and the US, with roughly 100 million hectoliters produced annually. Beer breweries generate effluents of the order of 2 to 6 liters per liter of the final product (UNIDO, 2020 a).

Most sewage comes from domestic, industrial, agricultural, and hospital wastewater, corresponding on average to 80 percent of the total volume of drinking water consumed. Wastewater is often improperly disposed of in natural bodies of water and pollutes waterways, while a fraction in developing countries is processed at treatment plants. Most of the sewage sludge generated at wastewater treatment plants constitutes a significant fraction of the total organic matter and energy not recovered in the treatment process. Wastewater is rich in nutrients like nitrogen, phosphorus, potassium, calcium, and magnesium, and fertilizer and biogas can be generated using suitable treatment practices (Cañote et al., 2021).

Biogas production was opened by substrate into Agriculture and Cattle (BIOAGR), Slaughterhouses (BIOSLA), Flour Mills (BIOMIL), Sugar and Alcohol (BIOSUG), Beer breweries, dairy and other food processors (BIOFOO) and Solid waste and sewage treatment (BIOWAS). The surveys account for 94.3 million Nm3 biogas production for the South Region (three states) and 1,994 total employments generated. See Table 1.

Table 1: Primary data on surveyed biogas producers

Biogas Sector	Total PR	Total RS	Total SC	Total South Region
Production (Millions of Nm3 of biogas)	76.97	6.64	7.68	94.31
Total employment	1,252 (a)	182	560	1,994
Biogas factory workers	95 (b)	26	41	162

(a) and (b) were corrected for outliers.

Source: Authors' elaboration on CiBiogas and GEF Biogás Brasil Surveys.

We then estimated the employment coefficients and expanded the sample data to include the population. Calling "L" the employment, "Nm3" the biogas production in physical units, and "GPV" the Gross Production Value in 2018 US$, we could generate "L/Nm3" as the coefficient employment/physical production of biogas and "L/GPV" as the coefficient employment/economic value of production. We applied these coefficients from sample data to the GPV of the regional IO Matrices (see below) to compute total employment in each biogas sector.

Table 2. Expansion of surveyed data (size sample = n) in the biogas sector (size sample = N).

Biogas Sector	Companies in the Samples A	Biogas Production in Millions of Nm3 (n) B	Biogas Production in Millions of Nm3 (N) C	Biogas Factory Workers (n) D	Biogas Factory Worker / Millions of Nm3 (n) E = D/B	Expanded Biogas Factory Workers (N) F = C x E	Biogas Factory Workers + Biogas Office Workers G = F x 2.92 ****
BIOAGR	52	24.374	59.597	108	4,4	264	771
BIOSLA	5	6.461	28.861	17	2,6	76	222
BIOMIL *	18	46.530	22.147	30	1,4	30	88
BIOSUG **	-	-	65.489	-	2,2	141	413
BIOFOO	1	0.438	5.809	2	4,6	27	77
BIOWAS ***	1	16.532	121.042	255	5,4	659	1,923
Total	64	94.334	302.945			1,197	3,494

*Column E = D/C.
** In the BIOSUG sector there is no sample data to relate Production with Biogas Factory Workers. We applied the employment/production coefficient for Brazil's entire sugar and alcohol sectors.
*** In the BIOWAS sector employment we imputed from a conservative assumption based on units of biogas production of SANEPAR, the water and sanitation company for the PR state.
****To expand biogas factory workers to total biogas workers (that is, adding office workers), we expand using the coefficient 2.92 from Perrotta's (2021) study on biomass (1.92 office workers per factory worker).
Source: Own elaboration based on CiBiogás and GEF Biogás Brasil surveys and Perrotta (2021).

The calculations were quite straightforward in some sectors (BIOAGR, BIOSLA, and BIOFOO), while we needed some additional assumptions in the others (BIOAGR, BIOSUG, and BIOWAS). In the first three sectors, production can directly relate to employment (both total and biogas factory workers' subset) from Table 1. The biogas factory workers in the three states are 1,197 persons and the total workers are estimated at 3,494 workers (office plus plant).

4. Methodological Approach

Our first contribution is methodological. To study a small and modern sector, not disaggregated in official statistics, we use a bottom-up approach incorporating information on the cost and sales of different biogas value chains to study an economy where only national and highly aggregated regional Input-Output (IO) matrices are available.

An IO matrix is a basic input in building IO Models, which, in its simplest form, is a system of n linear equations with n unknowns, whose main goal is analyzing changes in demand or other inter-sectoral relationships. The IO Models are built from information contained in an IO Matrix containing information on intersectoral flows, the structure of final demand, and the value added in the different sectors. In addition to primary information reported in the previous section, we also have secondary information which includes national and state-level statistics of different dates and levels of aggregation. In no case was biogas considered a disaggregated sector, nor was it possible to determine its employment generation.

We use a physical satellite account Table for employment. We consider satellite accounts to be a first step in modeling employment creation. Also, a sensible approach could be to disaggregate products and sectors into more detailed categories, which presents a challenge because sectoral data may not be available at the required level of detail.

There are three main approaches to regionalizing Input-Output Tables: 1) Direct techniques employing mainly surveys and specific data of a strictly sectoral nature (usually expensive and time-consuming); 2) indirect or statistical techniques resting mainly on available secondary sources (often inaccurate); 3) a hybrid mix of the two methods (since the problem is focused on a few sectors for which primary data are available to add to secondary and more aggregated information) (Rojo et al., 2020).

The availability of an Input-Output Table, in turn, makes it possible to develop Social Accounting Matrices or SAMs. They are matrices in which rows (incomes) and columns (outflows) represent markets and institutions, and whose elements represent the transactions in the input and output markets while considering and accounting for interactions between government, firms, households, and the rest of the world (Miller and Blair, 2009). They represent national accounts' data about final consumption and value-added in an expanded and more detailed way than Input-Output Tables.

The Input-Output Table is based on location quotients (LQs). LQ techniques assume that regional technologies have the same structure as national ones but admit that interregional coefficients differ from national ones by a shared factor in regional trade, assuming the greater the region, the lower its import propensity. The surveys (primary information added to secondary, aggregate data) allow us to improve LQs using RAS or Cross-Entropy techniques (Flegg et al., 1995; Lahr, 1993; Stone, 1977).

In addition to the national Input-Output Tables, the location quotients use existing statistics on employment or value added. Regional and national data should be compatibilized, updated, and aggregated at the same level. There are many applications of such regional indirect methods for Mexico (Dávila Flores, 2015); Finland (Flegg and Tohmo, 2013; Kowalewski, 2015); Greece (Kolokontes et al., 2008); Germany (Kronenberg, 2009); and Argentina (Flegg et al., 2016; Romero et al., 2020, Romero et al., 2023 a and b), among others. Szabó (2015) presents an extensive survey of location quotient methods.

We use FLQ (Flegg LQ) because its theoretical ground is more plausible than other LQ methods (Flegg et al., 2016). Additionally, the Flegg and Webber (2010) evaluation of LQ techniques highlights that FLQ and Augmented FLQ (AFLQ) are preferable quotients, providing satisfactory results even for small regions. In addition, although the AFLQ is theoretically better than the FLQ, in practice they perform similarly according to Bonfiglio and Chelli (2008), Kowalewski (2015), and Lamonica and Chelli (2019).

The information from LQ is used jointly with a regional transaction matrix estimated via indirect methods. To ensure consistency between both sets of data, we use matrix balancing methods (RAS and/or cross-entropy) for the final adjustment. The above-mentioned RAS or method of bi-proportional adjustment is an iterative process that implies knowing row and column totals to adjust an initial matrix (Bacharach, 1970). The cross-entropy method, not employed here, on the other hand, minimizes a distance measure between an initial matrix and different calculated matrices meeting technological and transactional restrictions (Robinson et al., 2001, McDougall, 1999).

Our second contribution is empirical. Thus, we 1) compiled all the information, 2) made compatible sectors and dates, 3) produced the new sector entries in the matrix, 4) developed satellite accounts for employment coefficients, and 5) calibrated the input-output models we needed. Then, 6) we ran simulations and applied some sensitivity analysis to the former.

However, we had to add primary information on biogas production and employment to resolve points 4) and 5). We had information from two complementary surveys, which we identify as “CiBiogas” and “GEF Biogas Brasil”, following UNIDO (2023). Both surveys were conducted at the productive unit level. The first one focused on technology and production, and the second on investments and employment. By combining primary and secondary data on biogas, we were able to estimate the regional IO matrices with the entries we needed. Furthermore, we estimated the IO matrix that represents inter-industry relationships in the states based on national and state-level information and opens the biogas sector according to those surveys through indirect methods (Jensen et al., 1979; Flegg and Webber, 1997). Once the IO matrices and the biogas and employment satellite accounts were built, we were able to estimate the direct, indirect, and induced effects of increased demand, supply capacity, and substrate processing in the biogas sector using open and closed IO Models.

4.1. Regional Input-Output Model

We used an IO model based on regional coefficients to make a detailed analysis of how a given shock directly affects biogas and other related sectors.

The resolution is identical in both the regional and national models. According to the “open model”, all final demand is exogenous: private consumption, public expenditure, investment, and exports. This means that the increase in household income because of greater output does not cause additional (“induced”) demand due to greater consumption. The regional “open model” is as follows:

$$\mathrm{x}^{\mathrm{r}} = (\mathrm{I} - \mathrm{A}^{\mathrm{rr}})^{-1}\mathrm{f}^{\mathrm{r}} = \mathrm{L}^{\mathrm{rr}}\mathrm{f}^{\mathrm{r}} \ , \qquad (1)$$

Where x^{r} is the production vector of the region, I is the identity matrix, A^{rr} is the matrix of the region’s technical coefficient, f^{r} is the region’s final demand vector, including purchases from other regions, r is the number of sectors, and L^{rr} is the requirement coefficients’ Leontief matrix, both direct (initial) and indirect (secondary).

We “close” the model by including households as just another sector of the model. The “closed model” thus changes to:

$$\bar{\mathrm{x}}^{\mathrm{r}} = (\mathrm{I} - \bar{\mathrm{A}}^{\mathrm{rr}})^{-1}\bar{\mathrm{f}}^{\mathrm{r}} = \bar{\mathrm{L}}^{\mathrm{rr}}\bar{\mathrm{f}}^{\mathrm{r}} \ , \qquad (2)$$

Where $\bar{\mathrm{x}}^{\mathrm{r}}$ is the region’s production vector including household income in the last row, I is the identity matrix, $\bar{\mathrm{A}}^{\mathrm{rr}}$ is the technical coefficient matrix showing household income in the last row, and household expenditure in the column on the right, $\bar{\mathrm{f}}^{\mathrm{r}}$ is the vector for the remaining final demand (without household consumption in the region), r is the number of sectors, and $\bar{L}^{rr}$ is the Leontief matrix for direct, indirect and induced (tertiary) requirement coefficients.

In addition to the simple product multipliers resulting from the "open model" (type 1 multiplier) and total product multipliers resulting from the "closed model" (type 2 multipliers), we also estimated job multipliers. Job multipliers are obtained by changing the measurement unit of the coefficients in matrices L^{rr} and $\bar{L}^{rr}$, using, for instance, the number of persons employed per product unit. These employment multipliers compute the number of jobs that the production increase generates.

4.2. Regional Input-Output Tables

To build Regional IO Tables we had an official IO matrix for Brazil, two official IO matrices for PR and RS, and an academic study with an IO matrix for SC, plus sectoral information on physical production and employment. Nevertheless, first, the information was inadequate. Second, the IO matrices differed by the time they were built. Third, the disaggregation of the sectors was different and insufficiently detailed for our purposes, and fourth, there was a general need for matching.

The information from LQ was used jointly with a regional transaction matrix estimated via indirect methods. We use RAS to ensure consistency between both sets of data. The latter, a specific instance of cross-entropy according to McDougall (1999), is more flexible as it enables us to include more constraints in regional technical coefficients to make an estimation.

For Brazil as a whole, we used the Input-Output Matrix for 2015 of the IBGE with 67 sectors (https://www.ibge.gov.br/estatisticas/economicas/contas-nacionais/9085-matriz-de-insumo-produto.html). We have developed these entries because some sectors besides the biogas producers are also relevant to the biogas chain, and they are not open in the IBGE matrix. These include bovine, porcine, and poultry (included in cattle), beer, flour, sugar, and alcohol (in manufacture), urban solid waste, and sewerage treatment.

For RS and PR there are regional IO Matrices for 2008 and 2015, respectively. However, there are far fewer sectors than the national matrix (37 and 42). They were developed by the Fundação de Economia e Estatística (FEE) in RS (https://arquivofee.rs.gov.br/indicadores/pib-rs/matriz-insumo-produto-rs-miprs/mip-rs-2008/) and by the Instituto Paranaense de Desenvolvimento Econômico e Social (IPARDES) in PR (https://www.ipardes.pr.gov.br/Pagina/Matriz-Insumo-Produto). These matrices, as well as the national ones, were updated to the 2018 values. Given the absence of an official matrix in SC, we developed it by applying indirect methods based on Haddad (2018).

To update the information to the year 2018 in the three states we used sector and activity information published by the Sistema de Contas Regionais do IBGE open into 18 sectors (https://www.ibge.gov.br/estatisticas/economicas/contas-nacionais/9054-contas-regionais-do-brasil.html?edicao=34530). In PR and RS, and because of the existence of earlier matrices, they were updated by the RAS method, where the borders were corrected with data published for the region in 2018. For SC, the matrix was estimated through indirect methods referenced on data of GVP and intermediate consumption. The entries for the four matrices were made compatible in 35 sectors, including six for biogas production, and those related producers of maize, manioc, sugar cane, bovine, porcine, poultry, slaughterhouses, flour mills, alcohol from sugar cane, beer breweries, dairy, and other food industries. The entries are listed in Table 3, together with their corresponding GVP (in thousands of US$ and percentages).

The estimate of the Employment Vector for the three states' IO Matrices was based on IBGE's "Pesquisa Nacional por Amostra de Domicílios Contínua" or PNAD Contínua (https://www.ibge.gov.br/estatisticas/sociais/trabalho/9171-pesquisa-nacional-por-amostra-de-domicilios-continua-mensal.html), which is the best source to estimate both formal and informal employment within the sector and the geographic disaggregation that the study needed. The estimates of employment for each sector correspond to the average of the four quarters in 2018 and include all persons who worked at least one hour in a remunerated activity (formal or informal) during a reference week for each survey. The sample data for each state were expanded to the total population using weights provided by the survey (Variable V 1028). Time classification is a 5-digit disaggregation of "Classificação Nacional de Atividades Econômicas Domiciliares 2.0." We were then able to build a correspondence table for each group's employment according to the sectoral disaggregation of the IO Matrices of each state.

The employment vector for each state was calculated as a satellite account, see Table 3. The table presents the number of workers employed in each sector in each state and the region, and the coefficient of job creation by a unit of GPV.

Table 3: Homogeneous Sectors in the Input-Output Matrices of the Southern States in Brazil

Sector	**GPV**				**Employment / GPV**			
	PR	**SC**	**RS**	**South**	**PR**	**SC**	**RS**	**South**
Maize	0.311%	0.119%	0.137%	0.204%	41.71	99.90	73.89	57.14
Cassava	0.049%	0.013%	0.007%	0.025%	85.58	179.81	292.50	118.55
Sugar cane	0.171%	0.001%	0.002%	0.070%	35.30	29.94	86.56	35.95
Bovine Cattle	0.092%	0.061%	0.130%	0.100%	435.57	799.43	352.01	440.79
Swine Cattle	0.131%	0.338%	0.199%	0.201%	20.64	29.56	16.92	22.38
Poultry	0.289%	0.196%	0.224%	0.245%	26.39	71.10	23.30	32.84
Biogas from Cattle	*0.002%*	*0.004%*	*0.001%*	*0.002%*	*54.55*	*54.60*	*54.48*	*54.56*
Rest of Agriculture, Forest, and Fishing	5.401%	3.501%	6.198%	5.308%	18.75	31.15	21.34	21.63
Extractive Industries	0.656%	0.560%	2.555%	1.365%	5.26	5.53	1.36	2.48
Meet food industry	4.327%	2.504%	2.188%	3.122%	6.86	17.89	9.26	9.37
Biogas from slaughterhouses	*0.002%*	*0.000%*	*0.001%*	*0.001%*	*27.44*	*26.81*	*27.35*	*27.36*
Mills sector	0.002%	0.002%	0.000%	0.001%	22.16	19.97	37.97	22.1
Biogas from Mills	*0.002%*	*0.000%*	*0.000%*	*0.001%*	*14.96*	*11.24*	*0.00*	*14.93*
Sugar and Alcohol	0.401%	0.000%	0.000%	0.163%	7.88	886.98	1798.47	8.69
Biogas from Sugar and Alcohol	*0.005%*	*0.000%*	*0.000%*	*0.002%*	*23.86*	*0.00*	*25.56*	*23.87*
Beer	0.262%	0.772%	0.552%	0.481%	8.43	4.63	8.87	7.34
Biogas from Beer, Dairy, and other Food	*0.000%*	*0.000%*	*0.000%*	*0.000%*	*47.25*	*42.57*	*46.51*	*47.14*
Oil and Gas Refineries, Petrochemical Ind.	16.918%	1.381%	11.889%	11.720%	0.85	5.92	0.49	0.83
Machines and Equipment, incl. Maintenance	2.801%	2.486%	3.866%	3.144%	5.21	16.09	5.60	7.20
Automotive Industry	4.707%	1.570%	5.467%	4.340%	2.63	6.78	2.13	2.70
Rest of Manufacturing	20.908%	34.150%	23.306%	24.613%	7.75	11.02	8.42	8.95
Electricity	1.779%	1.935%	1.234%	1.602%	2.51	2.69	4.57	3.17
Biogas from Sewerage and Solid Urban Waste	*0.004%*	*0.001%*	*0.007%*	*0.005%*	*50.80*	*50.99*	*50.78*	*50.80*
Distribution of Electricity, Gas, and Water	1.779%	0.858%	2.103%	1.710%	1.63	4.71	1.71	1.99
Construction	3.693%	4.963%	2.675%	3.569%	35.96	29.36	46.04	36.94
Commerce	8.265%	10.741%	8.110%	8.726%	37.98	34.22	39.36	37.50
Transport, Store, and Mail	5.198%	5.966%	4.009%	4.902%	17.44	16.14	22.16	18.59
Hotels and Restaurants	1.264%	2.031%	1.486%	1.511%	62.24	44.44	51.91	53.31
Information and Communication	2.485%	2.722%	2.746%	2.635%	9.77	11.47	8.30	9.55
Finance, Insurance, and Connected Services	2.612%	2.654%	3.799%	3.077%	8.02	11.11	6.07	7.66
Real Estate	3.208%	4.473%	3.280%	3.502%	3.43	3.40	4.23	3.71
Professional, Scientific, and Technical Services	3.355%	4.044%	3.080%	3.394%	53.81	51.38	62.44	56.21
Public Administration, Defense, Education, Health	5.526%	7.459%	8.752%	7.172%	46.25	40.98	34.04	39.37
Art, Culture, Sports, Recreation and Other Services	3.057%	4.012%	1.866%	2.801%	5.43	5.16	10.58	6.67
Domestic Services	0.337%	0.481%	0.131%	0.288%	299.70	190.70	807.27	350.04
TOTAL BIOGAS	*0.015%*	*0.005%*	*0.009%*	*0.011%*	*34.47*	*52.16*	*49.25*	*41.14*
TOTAL (MM USD)	**327,963**	**169,944**	**310,592**	**808,499**	**16.51**	**20.94**	**17.57**	**65.22**

Sources: MIP Nacional 2015 (Instituto Brasileiro de Geografia e Estatística IBGE), Valores Brutos de Produção 2018 (IBGE), MIP Regional Paraná 2015 (Instituto Paranaense de Desenvolvimento Econômico e Social IPARDES), MIP Regional Rio Grande do Sul 2008 (Fundação de Economia e Estatística FEE), Fatores de Conversão e Potenciais 2019 (GEF Biogás Brasil), Parâmetros Técnicos e Dados dos Setores de Biogás 2019 (GEF Biogás Brasil), Quantidades, Preços e VBP Setoriais 2017 (Censo Agropecuário IBGE), Produção Setorial 2019 (Produção Agrícola Municipal PAM), Preços Setoriais 2018 (Pesquisa de Orçamentos Familiares).

The models incorporate some technological parameters to develop the economic numbers. We develop converters of biogas produced per ton of processed substrate following Mariani (2019), aggregated to sector level, as a weighted average of the different substrates processed by each sector. In the case of cattle, the coefficient is different in the three states, while it is uniform for the three states in the rest of the sectors. For the electricity generated by m3 of biogas, we used a uniform technical value of energy efficiency in the conversion of 1.51 kWh/Nm3. We established the cost of one unit of 1 MW of equivalent productive capacity obtained from biogas at 2018 US$ 3.13 million (UNIDO, 2023). Self-consumption of electricity was assumed at 90 percent on average for all sectors and states, the rest being sold or (minimally) enriched to produce biomethane. The conversion of Nm3 of biogas produced in employment is 8.51 jobs/Nm3 on average for the South Region.

Table 4: Technical Coefficients for Conversion

Place	Sector	Biogas production per unit of the substrate (Nm3 / tons)	Employment generated by a unit of biogas produced (jobs / Million Nm3)
PR	BIOAGR	47.23	9.28
SC	BIOAGR	35.83	18.02
RS	BIOAGR	40.88	18.85
South Region	BIOSLA	98.62	9.45
South Region	BIOFAR	5.90	5.16
South Region	BIOSUG	13.43	2.37
South Region	BIOFOO	82.92	56.67
South Region	BIOWAS	NA	17.54
South Region	TOTAL		8.51

Source: Own elaboration based on "CiBiogás" and "GEF Biogás Brasil" surveys, Freddo et al. (2019). Mariani (2019) for conversion factors, and UNIDO (2023) for investments.

Table 5 presents the baseline for the sector and the state of the initial calibrated model. The biogas sector generates 303 million Nm3 biogas in the South Region, equivalent to 457,500 MWh of electricity generation, a GPV of 2018 US$ 85 million, and a Value Added (VA or GGP –Gross Geographic Product-) of 2018 US$ 14 million. Since the composition of the biogas sector is different in each state, the relation between employment generation and VA or GPV varies in each state, reaching values of 252 and 41 jobs created per million in 2018 US$, respectively.

Table 5: Southern states of Brazil, 2018. Biogas and employment, by state

State	Biogas production (MM of Nm3 / year)	Electricity Equivalent (MWh)	Production Gross Value (MM of 2018 US dollars) (A)	Value Added (MM of 2018 US dollars) (B)	Jobs (C)	Jobs / GPV (C/A)	Jobs / VA (C/B)
Parana	196.02	295,985	48.00	8.02	1,669	34.77	208.10
Santa Catarina	27.98	42,251	9.22	1.29	481	52.17	372.87
Rio Grande do Sul	78.95	119,211	27.27	4.55	1344	49.28	295.38
South	302.95	457,447	84.90	13.86	3,494	41.15	252.09

Source: Own elaboration based on processed primary information from "CiBiogás" and "GEF Biogás Brasil" surveys and processed secondary information (see references in Table 3).

The biogas sector is small in terms of the economies and the employment of the three states: its GPV is 0.01 percent of 2018 US$ 808.5 billion produced by the three states, and the jobs created report only 0.024 percent of the employment in the South Region. Nevertheless, the generation of employment per unit of GPV more than doubles the average of the economy.

5. Scenarios and Results

5.1. Scenarios

We devised three scenarios linked to three questions:

1) What would happen with production and employment in the biogas sector if the (current) idle capacity were used completely?
2) What would happen with production and employment in the biogas sector if current capacity were doubled?
3) What would happen with production and employment in the biogas sector if all biomass generated in the country's South Region were employed to produce biogas?

We can imagine the first scenario as a response to a shock, for example, if a significant rise in fossil fuels were to occur; the second one can be assimilated by some policy that guarantees that all production would be sold; the third scenario is more hypothetical and related to more demanding environmental demands, for example, related to emission control commitments to the international community.

We called the first scenario Demand Pull, and since idle capacity is roughly 50 percent, it is equivalent to a 100 percent increase in sales. The second scenario is one of Supply Push, and the hypothesis is a 100 percent increase in capacity (and full capacity utilization). The third scenario is called Full Use of Substrate. The third scenario demands considerably greater investments than the second. The second and third scenarios differ from the first in the weight of investments which demands transient activity and job generation in the construction and implantation stages of the process, in addition to permanent production and employment once the plants have been built.

5.2. Results

The point of departure is a GPV of 2018 US$ 85 million in the South Region, employing 3,494 persons (1,197 biogas factory Workers and the rest office Workers). All scenarios include certain conservative assumptions on technical parameters: a constant intensity of job creation in the industry, a certain time rate of capacity utilization (including time for repairs and maintenance), the current relative prices for machinery, and a prudent energy potential generation of the biogas. Table 6 presents the aggregate results for each scenario, considering direct, indirect, and induced effects on production and employment.

Table 6: Results of Production Increase (in millions 2018 US$) and Gross Employment Increase (jobs)

Scenario	Production Increase					Gross Employment Increase				
	Direct	Indirect	Induced	Total	Multiplier	Direct	Indirect	Induced	Total	Multiplier
Scenario 1: Demand Pull	83.3	104.1	101.9	289.3	3.47	3,605	2,484	1,819	7,908	2.19
Scenario 2: Supply Push	530.6	468.9	636.2	1,635.7	3.08	13,163	9,077	11,016	33,256	2.53
Scenario 3: Full Use of Substrate	3,979.6	3,728.7	5,031.9	12,740.2	3.20	109,030	82,175	92,433	283,638	2.60

Source: Own elaboration

If idle capacity is fully employed, GPV increases by 2018 US$ 83 million as a direct consequence, 104 million considering indirect effects, and 102 million by induced effects.

The total increase is 289.33 million or 247 percent, and the maximum potential for job creation reaches 8,840 employees.

Instead, if capacity is doubled, given that all production is sold, the total increase in production is 2018 US$ 1,635 million and the creation of 33,255 jobs. This occurs because the new plant's construction contributes to the generation of several jobs in construction, equipment, transportation, etc.

Lastly, if all (currently) available biomasses were used, the increased production would increase to 2018 US$ 12,740 million (or 4.53 percent of the GPV of the region), and total job creation would be 283,637 (or 2 percent of total employment in the region).

In Table 7 the results for the direct effects on production and employment are presented by state and in Table 8 are presented by biogas subsector within each state. Finally, in Table 9 the information contained in Tables 7 and 8 is crossed for job creation, showing employment increase in each state and each biogas subsector.

The effects of the demand-pull scenario 1 are modest, and its effects are more intense in the PR state. Production and employment virtually doubled from the initial levels since the capacity utilization at the beginning of the exercise is roughly half of the industry potential. In the supply push scenario 2 the increase in production and employment is greater than in the former case for several reasons: it assumes that all production is sold, full idle initial capacity is employed, and brand-new capacity is built and employed. Moreover, there is a significant increase in production and employment which is transient in the construction phase of the new capacity building. Finally, the full use of substrate scenario 3 shows a very important growth in production and employment. This scenario assumes all substrates are used, all capacity needed is built and all production is sold, which is very ambitious and unrealistic, nevertheless, it is useful to calculate the full potential of the sector. Direct and total effects are shown. In scenarios 2 and 3 the total effects are more pronounced than in scenario 1 which does not include building of brand-new capacity. Since PR is the state with currently the idlest capacity, it concentrates the greatest share of changes both in production and employment in scenarios 1 and 2. However, since substrates are more evenly distributed among the three states in the current capacity, differences moderate in scenario 3, because of the different intensity of labor of each substrate and the different composition of the biogas sector in each state.

Table 7: Results of Production Increase (in millions 2018 US$) and Gross Employment Increase (jobs) by state

Scenario / State	Production Increase				Employment Increase			
	Direct	%	Total	%	Direct	%	Total	%
Scenario 1: Demand Pull								
PR	48.8	59%	161.8	56%	1,834	51%	3,602	46%
SC	20.4	24%	82.9	29%	1,096	30%	2,878	36%
RS	14.1	17%	44.7	15%	675	19%	1,429	18%
Scenario 2: Supply Push								
PR	363.0	68%	1,070.9	65%	8,759	67%	20,056	60%
SC	77.4	15%	294.9	18%	2,223	17%	7,243	22%
RS	90.2	17%	269.8	16%	2,180	17%	5,957	18%
Scenario 3: Full Use of Substrate								
PR	1,673.7	42%	4,925.1	39%	41,430	38%	93,728	33%
SC	1,046.8	26%	4,003.2	31%	30,630	28%	96,118	34%
RS	1,259.1	32%	3,812.0	30%	36,970	34%	93,791	33%

Source: Own elaboration

Table 8 shows the same results but with different degrees of detail. Instead of opening results by state, they are open by subsector of biogas. In agriculture most of the current idle capacity is concentrated, and potential for production and employment growth. However, when the consideration is focused on the greater potential for growth, solid waste and wastewater have the same potential as agriculture. In practice, one-third of the production and employment potential can be adjudicated to agriculture, one-third to industry, and one-third to solid waste and wastewater.

Table 8: Results of Production Increase (in millions 2018 US$) and Gross Employment Increase (jobs) by type of biogas

Scenario / Type of Biogas	Production Increase				Employment Increase			
	Direct	%	Total	%	Direct	%	Total	%
Scenario 1: Demand Pull								
BIOAGR	42.7	51%	154.4	53%	2,327	65%	5,013	63%
BIOSLA	11.2	13%	36.8	13%	306	8%	697	9%
BIOFAR	2.5	3%	8.4	3%	37	1%	158	2%
BIOSUG	16.0	19%	55.6	19%	383	11%	1,060	13%
BIOFOO	1.5	2%	4.7	2%	72	2%	118	1%
BIOWAS	9.5	11%	29.5	10%	481	13%	862	11%
Scenario 2: Supply Push								
BIOAGR	200.7	38%	648.8	40%	5,661	43%	14,484	44%
BIOSLA	60.7	11%	181.7	11%	1,331	10%	3,309	10%
BIOFAR	28.2	5%	84.4	5%	518	4%	1,506	5%
BIOSUG	113.4	21%	341.2	21%	2,378	18%	6,033	18%
BIOFOO	9.8	2%	28.7	2%	267	2%	577	2%
BIOWAS	117.9	22%	350.9	21%	3,008	23%	7,348	22%
Scenario 3: Full Use of Substrate								
BIOAGR	1,227.5	31%	4,068.0	32%	37,402	34%	99,173	35%
BIOSLA	548.0	14%	1,779.6	14%	12,221	11%	35,160	12%
BIOFAR	195.9	5%	620.0	5%	3,584	3%	11,782	4%
BIOSUG	467.8	12%	1,409.5	11%	9,817	9%	28,437	10%
BIOFOO	117.0	3%	369.8	3%	3,382	3%	8,043	3%
BIOWAS	1,423.4	36%	4,493.4	35%	42,623	39%	101,042	36%

Source: Own elaboration

Table 9 crosses information from Tables 7 and 8, considering only employment and percentages. It is useful to assess the location of job gains by subsector and state. In scenario 3 each state participates in one-third of total employment, while in scenarios 1 and 2, which are proportional to current capacity, most of employment is generated in PR.

The First Scenario is quite possible to attain. The second implies heavy investments and the third scenario is highly hypothetical and should be considered an intellectual exercise. However, it shows the potential maximum capacity of biogas production if the biomass supply is exhausted.

Table 9: Results of total gross employment Increase (jobs) by type of biogas and state

Scenario 1: Demand-Pull Subsector	PR	SC	RS	Total
BIOAGR	21%	35%	8%	63%
BIOSLA	6%	1%	2%	9%
BIOFAR	2%	0%	0%	2%
BIOSUG	12%	0%	1%	13%
BIOFOO	1%	0%	0%	1%
BIOWAS	3%	1%	7%	11%
Total	46%	36%	18%	100%

Scenario 2: Supply Push Subsector	PR	SC	RS	Total
BIOAGR	20%	20%	4%	44%
BIOSLA	8%	0%	2%	10%
BIOFAR	4%	0%	0%	5%
BIOSUG	18%	0%	0%	18%
BIOFOO	1%	0%	0%	2%
BIOWAS	9%	2%	11%	22%
Total	60%	22%	18%	100%
Scenario 3: Full Use of Substrate Subsector	**PR**	**SC**	**RS**	**Total**
BIOAGR	7%	17%	11%	35%
BIOSLA	3%	4%	5%	12%
BIOFAR	3%	1%	0%	4%
BIOSUG	8%	0%	2%	10%
BIOFOO	1%	1%	1%	3%
BIOWAS	11%	11%	14%	36%
Total	33%	34%	33%	100%

Source: Own elaboration

6. Conclusions

We aim to measure the current and potential production and employment in the biogas value chain in three southern states in Brazil (Paraná, Santa Catarina, and Rio Grande do Sul), motivated by the growing importance of renewable energies to cope with SDGs, and the potential of these states to produce biogas since biomass abundant sources and convenient tropical climate.

We offer two contributions. First, we examine a method to study the problem of determining how to measure production and gross job creation in regional economies with differently opened sectoral entries and periods of measurement in sectors that are not currently disaggregated and need primary data to complete the information, as well as construct coherent monetary (production) and physical units (employment). Second, we estimate direct, indirect, and induced production and (gross) employment for the biogas-producing sectors in the South Region. In doing so, we calibrate an Input-Output Model for each state with the biogas sectors now included as separate activities, produce simulations of interest for policymakers, and apply some sensitivity tests.

Thus, one dimension of our analysis is the combination of monetary with physical units, while the other one is regionalization. Our method calibrates regional IO matrices of the three states with compatibilized sector entries, opening new ones for those missing in official statistics (secondary data) from primary specific data from surveys. Once the baseline has been established, we consider three scenarios: demand-pull that achieves full capacity utilization, supply push that addresses new investments in the sector, assuming guaranteed demand, and the use of the full potential of substrate generated for biogas production.

For the three southern states in Brazil – Paraná, Santa Catarina, and Rio Grande do Sul – our estimates of Gross Value of Production total US$ 85 million, Value Added reaches US$ 14 million, direct gross employment amounts to 3,494 workers, and indirect and induced gross employment is 7,261 jobs in the baseline. In the demand-pull scenario, all job creation registers 8,840 workers, while in the case of duplication of current capacity (assuming its full utilization) jobs created number 33,255. On the other hand, in the highly hypothetical case of full use of all substrates currently generated to produce biogas, gross job creation reaches 283,637 workers. Employment multipliers are in line with the literature on comparative activities from elsewhere in the world.

We offer a methodological approach to measure the current and expected contributions of the biogas subsector facing shocks (exogenous or induced by policies) in terms of product, and gross employment. As general conclusions: 1) the biogas industry is more labor intensive than other energy industries (for comparable energy units); 2) it creates jobs in concentrated points (such as a sewerage plant for a large city) or in sparse points in the country (farms), of different scales; 3) it directly employs skilled and non-skilled blue and white collar workers; 4) it indirectly employs people to build plants, equipment and machinery, to provide transportation, repairing and other commercial or general services; 5) it provides green jobs, in "circular" activities, taking advantage of substrates otherwise wasted and, thus, reducing emissions of GHG.

A limitation of the study is related to the current role of biogas as a complement to other sources of energy. If the sector gains scale and its commercial use replaces its current overwhelmingly self-consumption, it can transform into a substitute for fossil fuels. Thus, employment created in the biogas sector would replace some jobs in the fossil fuel industry, even though the net effect is expected to be positive since the biogas sector is comparatively more labor-intensive than oil and natural gas. Besides, a possible extension of this paper is to estimate the GHG emissions that biogas contributes to saving by replacing fossil fuels.

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