NET JOBS GENERATION AND NET GHG EMISSIONS REDUCTION FROM PARTIAL REPLACEMENT OF FOSSIL FUELS WITH RENEWABLE ENERGY SOURCES IN SOUTHERN BRAZIL

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Abstract

In this paper, we explore the reach of net job creation and net emissions reduction from the partial substitution of conventional (fossil) energy sources by renewables in Southern Brazil. We examine a subset of renewable energy sources, namely, biogas. It has been established that biogas requires lower investment and is also more labor-intensive than fossil energies for comparable units. However, gross job generation does not account for job losses in reducing sectors. In order to account for production and industrial chain relationships, input-output analysis allows for ordering information and tracing the interrelations between industries. Concerning jobs and emissions, input-output tables and models are expressed in monetary units. In contrast, jobs are measured in units (full-time equivalent - FTE), and all greenhouse gas (GHG) emissions are in MtCO2e. These satellite accounts in physical units join Input-Output tables, transforming conventional into hybrid Input-Output analysis. Once the baseline is established (2018), we consider different scenarios of fossil fuel substitution by biogas and determine values for net job creation and net emissions generation. Results highlight the favorable impacts of the development of biogas to produce electricity generation in terms of greater production and net job creation while saving GHG emissions.

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

1. Introduction

The changes in the energy matrix toward renewable energy sources can imply complementarity or substitution of conventional sources. If the linkages between both sources were strictly complementary, and the renewables started from scratch, the jobs created in this new sector would be additional to those already existing in the conventional energy industry. However, if renewables were to partially substitute conventional energy, jobs in the renewable energy sector would replace part of the jobs in the traditional energy sector. In addition, if conventional energy sectors yield specific Greenhouse gas (GHG) emissions and are partly replaced by energy generated with lower GHG emissions, net GHG emissions would decrease in the economy. Some previous research estimated gross job generation of increasing production in this sector in Brazil (Ferro et al., 2024); however, our aim here is to calculate net job generation and net emissions of increasing electricity generation through biogas while partially replacing fossil power generation.

In this paper, we aim to explore the reach of net job creation and net GHG emissions reduction from the partial substitution of conventional energy sources by renewables in Southern Brazil. We consider alternative technologies with different labor productivity associated with each technique.

We examine a subset of renewable energy sources, namely, biogas. Biogas technology is gaining prominence as a renewable energy source, offering a sustainable solution for waste management and energy production (Solomon, 2013; Omer, 2017). This is generated from substrates derived from agriculture and cattle, agroindustry (slaughterhouses, flour, and sugar mills), urban solid waste, and sewerage treatment. Generically, biogas is produced from biomass. 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 mainly comprises methane (50-75%), carbon dioxide (25-50%), steam, and other gases in low concentrations, such as hydrogen sulfide, hydrogen, and nitrogen.

Fossil fuels are globally responsible for more than 70 percent of GHG emissions, which explains global warming. Part of the solution is their progressive replacement with renewable energies.

Brazil is a middle-class country with an important industrial base, the tenth largest GDP by size globally, slightly below Canada and above Russia. Brazil has a relatively clean energy matrix, with an essential share of hydroelectricity, and a great potential for biogas production (82.6 billion m3 per year according to ABiogás, of which the current output 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 the Brazilian National Determined Contribution (NDC) to Paris Agreement targets, the country aims to reach a 45 percent share of renewable energies in its energy matrix by 2030 (Fundação Getúlio Vargas, 2019).

The Southern Region of Brazil consists of the states Paraná (PR), Santa Catarina (SC), and Rio Grande do Sul (RG). Together with the South-eastern, these states form part of the most developed regions of Brazil and have a very important biogas production potential because of their productive matrix: they are important producers of biomass from agriculture, cattle exploitation, the food industry (slaughterhouses, sugar and flour mills, beer breweries, etc.), plus solid waste and wastewater from urban centers.

Thus, the problem we tackle is calculating the net effect on employment and emissions in electricity production in the three southern states of Brazil of partially replacing electricity generation from fossil sources with biogas, given that part of the electricity generated through biogas is complementary. In contrast, the other part replaces electricity generated by fossil fuels. Brazil's electricity came from clean sources, with hydropower accounting for 60%. Fossil fuels represented about 9% of the 2023 electricity generation, producing 37.2 MtCO2e emissions. To deal with the problem at hand, we use input-output analysis. This methodology helps trace relationships between productive sectors. It can detect the transformation of raw materials into products, and with the convenient addition of satellite accounts, its links with physical biomass used, employment generated, and emissions yielded.

To solve the problem, there are several challenges to face: first, to develop disaggregated matrices at the state level (which implies, in turn, standardized practices and coherence with the national level); second, to introduce new sectors in the matrixes since biogas are generally not included (they are small sectors currently) and third, to develop satellite accounts for employment and GHG emissions. The two first tasks had been performed in past contributions (Ferro et al., 2024). The third was only partially fulfilled since job creation is estimated there, though job destruction for fossil fuel replacement was not addressed, nor was emission saved. These issues are faced with this paper.

Thus, we can estimate production, net employment, and net GHG emissions before and after a shock, considering increased production of biogas using existing biomass currently not employed, replacing conventional sources, creating and destroying jobs, and avoiding and generating GHG emissions under certain reasonable assumptions of technological choices.

We hypothesize that net job creation will be positive because biogas industries are more labor-intensive than fossil fuel energy generation. Beyond the bio-digestor operation, considerable work is involved in dealing with biomass. If investments are at stake, transient employment in building construction will also exist. The net GHG emissions will be lower than under the no-replacement case since biogas industries generate lower GHG emission levels than conventional energy sources.

This paper is organized as follows: after this Introduction, section 2 is for the literature review, contextual settings, data, method, and model, section 3 is for data, section 4 is for scenarios and findings, and section 5 is for conclusions.

2. Literature review, contextual settings, data, method, and model

2.1. Literature review

Our departing point is Ferro et al. (2024), where gross job creation is analyzed. The study first deals with a method to measure production and gross job creation in sectors not considered in the statistics because they are new or currently very tiny. After developing an Input-Output model to address the former in a regional economy, it estimates gross job generation in biogas activity. Since GHG emissions have reached dangerous levels that contribute to global warming, there are several initiatives to tackle the problem. At the macro level, the UN system initiatives for collective action. Its success is debatable because of the need for agreements and coordination. Nevertheless, they have contributed to sensibilizing the issue, putting the discussion on the table, and inducing scientific studies to evaluate the reach of the problem. According to IPCC, 2015, 73% of global GHG emissions are generated by the energy sector and 27% from the rest of the productive sectors. In 2015, China led the emissions generated (10,641,789 ktCO2), followed by the USA (5,172,336 ktCO2), the EU (3.469.671 ktCO2), India (2,454,968 ktCO2), and Russia (1,760,895 ktCO2) (Chandra Das, 2018). Global warming, the COVID-19 crisis, and the Russia- Ukraine conflict increased the concerns about energy use and its impact on sustainability, where bioenergy and agriculture have an important role to play (Martinho, 2023).

Since the energy sector is made globally mostly from fossil fuels, renewable energies are a response to reduce GHG from that origin. Brazil has a great, and currently underutilized, potential for renewable energy sources, and biomass production brings a potential to increase electricity from biogas, given the availability and diversity of substrates in the territory (Ferro et al., 2024). Martinho (2023) highlights the concept of “energy crops” since a great part of the contribution to renewable energies, particularly biomass, comes from agriculture.

Input-output modeling is an established technique to quantitatively address the economic impacts of changes in local economies (Pham et al., 2024). Economic activity has environmental impacts that extend to the supply chain from consumption to previous stages of production and distribution, and those effects can be traced in a model of that characteristics. However, the multiplicity of regional and sectoral interdependencies can be hard to trace, accounting for all impacts. In recent years, I-O models have been increasingly used to go beyond the economic consequences of shocks, incorporating environmental and social concerns such as employment. The sustainability goals require micro-level changes, sometimes induced by macro-trends or policies. In designing these policies, models of this type can yield informed views about the trade-off (Pham et al., 2024). IO analysis permits showing how the parts of a system are affected by changes in other parts. The literature distinguishes three main types of IO models: conventional (expressed in monetary units, MIO), physical (expressed in non-monetary units, PIO), and hybrid (expressed in both units, HIO) (Dietzenbacher et al., 2009; Miller & Blair, 2009). Towa et al. (2020) specifically analyze the literature using input-output models applied to waste management, also considering the functionalities of different models.

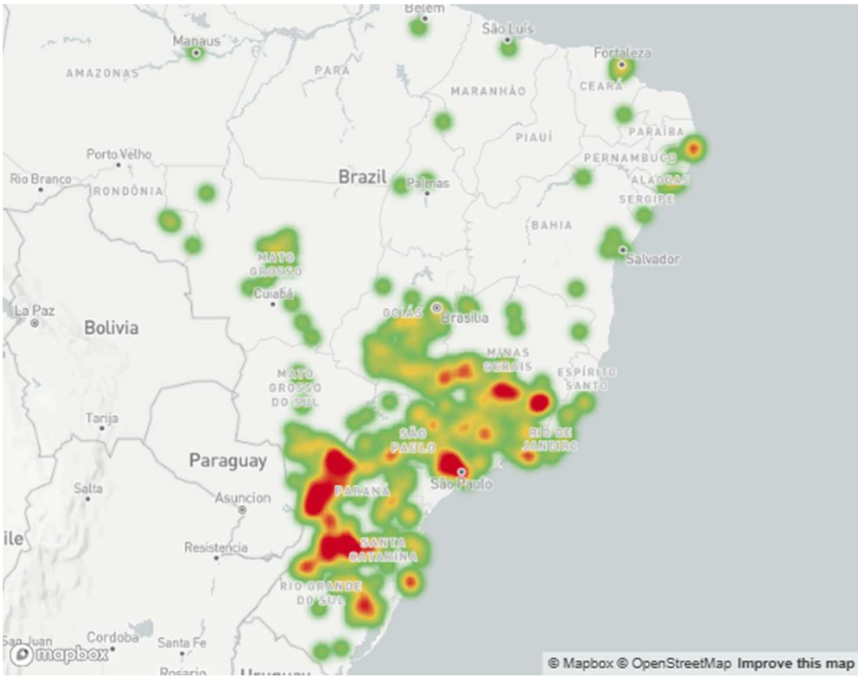
Net employment is the difference between the number of jobs created and the number of jobs lost at a given period. The net employment rate results from the difference between the job-creation and the job-destruction rates (Leonardo & Diniz, 2020). Vota (2022) observes that historically, it seems that innovation reduces employment in the short run while leading to a permanent increase in the long run in jobs of another character, defining innovation as new or improved products or processes. Also, the literature provides mixed evidence on the relationship between a firm’s innovation and employment rate.

2.2. Contextual settings

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).

Biogas holds significant potential in Brazil due to the country's vast biomass availability and diverse feedstock sources, including agricultural waste, livestock manure, and urban organic waste (Borges et al., 2021). Recent statistics indicate that Brazil can produce over 80 million cubic meters of biogas daily, primarily from livestock manure, representing nearly 70% of the total potential. The geographical concentration of biomass and biogas production is notably high in the South and Southeast regions, where most of the country's livestock and agricultural activities are located (See Map 1). The state of Paraná stands out as a leader in biogas production due to its extensive pig farming operations. Urban centers like São Paulo are also increasingly contributing to biogas production by utilizing landfill gas and wastewater treatment plants. Despite this potential, Brazil's current biogas production remains underutilized, with a growing focus on expanding infrastructure, technology transfer, and policy support to fully harness this renewable energy source for energy generation and waste management. (CiBiogás, 2021 and Fundação Getúlio Vargas, 2019). Brazil's biogas industry development faces challenges, including high upfront costs and a lack of supportive policies (Borges et al., 2021). To realize the country's biogas potential, the Brazilian government must address legal and regulatory issues and implement incentive programs to promote biogas production, transport, and sale (Pinto-Pires et al., 2015).

Map 1: Brazilian Overview of Biogas Plants (2022)



Source: https://cibiogas.org/ BiogásMAP

Many researchers have employed input-output analysis to assess the impact of environmental policy (Wang et al., 2019). However, a few articles specifically address the effects of biogas production on employment, the economy, and the environment at the regional or national level. In South Africa, biogas technology has shown positive socioeconomic impacts, including income generation, job creation, and improved energy access in rural areas (Rasimphi, 2024). In Finland, increased bioenergy use is projected to marginally lower GDP and employment levels while helping achieve emission reduction goals, with uneven regional distribution of costs (Simola et al., 2010). The Food and Agriculture Biomass Input-Output model (FABIO) is a comprehensive framework that traces global biomass flows and associated environmental pressures at a detailed product and country level (Bruckner et al., 2019). Multiregional Input-Output Analysis has been used to estimate the impacts of biomass logistics chain technologies, identifying the most stimulated sectors and highlighting the importance of biomass at a national level (de la Rúa et al., 2015).

Biogas technology has demonstrated significant socioeconomic impacts in rural areas (Omer, 2017). Studies in Kenya, Pakistan, the Czech Republic, and Nepal have shown that biogas yields substantial household financial savings, primarily through reduced fuel costs (Hamlin, 2012; Shams et al., 2014; Sigdel, 2020). A Danish study estimated that utilizing all available farm manure for biogas could create 3,420 jobs and generate substantial income (Sørensen & Jørgensen, 2022). However, biogas production can increase land lease prices and potentially crowd out traditional agricultural activities (Emmann et al., 2013).

Regional input-output models have been used to analyze the economic and environmental impacts of development in Brazil. Da Cunha & Scaramucci (2006) developed a mixed-technology model to assess the socioeconomic effects of bioethanol expansion, projecting significant GDP growth and job creation. Imori et al. (2011) employed an interregional input-output model to examine the trade-offs between greenhouse gas emissions reduction and economic development in the Amazon region, highlighting the dilemma posed by cattle and soybean production sectors.

2.3. Data

Biogas production was opened by substrate into agriculture and cattle, industry (comprehending slaughterhouses, flour mills, sugar and alcohol complex, beer breweries, dairy, and other food processors), solid waste, and sewage treatment. Our sources of information are those employed in Ferro et al (2024), where two surveys are mentioned: CiBiogás and GEF Biogás Brasil. The first is a production survey that accounts for the biogas production of 303 million Nm3. The second is an employment survey, which reports generating 1,087 total jobs. The second survey included the same list of firms surveyed, but only one subset declared their employment. We estimated the implied employment coefficient (jobs/MM NM3 = 11.53) and expanded data reaching 3,494 jobs (blue-collar plus white collar, where the relationship is 1.92 white collar per blue-collar, following Perrota, 2021) for the whole production.

Calling “L” the employment, “Nm3” the biogas production in physical units, and “VA” the Value Added in 2018 USD, we could generate “L/Nm3” as the coefficient employment/physical production of biogas and “L/VA” as the coefficient employment/value added. We applied these coefficients from sample data to the GVP of the regional IO Matrices to compute total employment in each biogas sector and region.

Table 1 presents the baseline 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 and a Gross Value of Production (GVP) of USD 85 million in 2018. Since the composition of the biogas sector differs in each state, the relation between employment generation and VA varies in each state, reaching average values of 252 jobs created per million of 2018 USD, respectively. The models incorporate some technological parameters to develop economic numbers. Following Mariani (2019), we developed converters of biogas produced per ton of processed substrate.

Table 1: Baseline. Biogas production, employment, GVP, and employment coefficients.

Biogas sector or Region	Biogas (MM Nm3)	Jobs (L in #)	Jobs per unit of biogas (L/MM Nm3)	Biogas Gross Value of Production (in MM 2018 USD)
Agriculture and cattle	59.597	771	12.94	22.23
Industry	122.306	800	6.54	24.81
Solid Waste and Wastewater	121.042	1,923	15.89	37.86
Total	**302.945**	**3,494**	**11.53**	**84.90**
Paraná	196.000	1,669	8.52	48.00
Santa Catarina	28.000	481	17.18	9.22
Rio Grande do Sul	78.900	1,344	17.03	27.27
Total	**302.945**	**3,494**	**11.53**	**84.90**

Source: Own elaboration based on CiBiogás and GEF Biogás Brasil surveys and Perrotta (2021).

The biogas sector is small in terms of the economies and the employment of the three states: its GVP is 0.01 percent of the GVP produced by the three states, and the jobs created report only 0.024 percent of the employment in the South Region. Nevertheless, the employment generation per unit of GVP is more than double (2.4) the economy's average (Table 2).

Table 2. Biogas in Southern Brazil. Production and installed capacity, 2018.

Sector	Unit	PR	RS	SC	South
Biogas production	Million Nm3	196	79	28	303
Agriculture and Cattle	Share %	17.93	6.53	69.00	19.67
Industrial*	Share %	58.16	8.61	5.36	40.37
Solid Waste and Wastewater	Share %	23.91	84.86	25.64	39.95
Installed Capacity Utilization	%	47	66	31	48
Use of biomass potential	%	9.31	5.79	2.51	6.61
Employment in biogas	Jobs	1,669	1,344	481	3,494
% of total employment	%	0.0308	0.0246	0.013%	0.0242

*Comprehending: Slaughterhouses, Mills, Sugar and alcohol, Beer breweries, and Dairy

Source: Own elaboration.

The information on GHG emissions from Brazil was obtained from the fourth national communication to the United Nations Framework Convention on Climate Change (UNFCCC) in 2020, with data from 2016. This inventory of GHG emissions is elaborated at the national level. Still, we must build GHG emissions satellite accounts at the state level and according to their sectoral production structure. To do so, we computed the intensity coefficients of GHG emissions per sector based on their production values at the national level. Assuming that the technology of production is the same across all states in Brazil and that the technologies do not change between 2016 (GHG Emissions Inventory) and 2018 (regional MIPs), we multiply the intensity coefficients of GHG emissions with the production of each sector in each state. This procedure also required a previous matching between the IPCC 2006 classification used in the GHG emissions inventories and the economic sector activities (ISIC classification rev.4) based on the recommendations of Eurostat (2015) for environmental-economic accounts. Brazil generates 989.83 MtCO2e, while the southern region accounts for 233.2 MtCO2e or 23.55%.

2.4. Method

To account for production and industrial chain relationships, Input-Output analysis offers good clues. This technique allows for ordering information and tracing the interrelations between sectors. 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 GHG emissions reduction, assessing the impact on the international markets, evaluating taxes and subsidy impacts, etcetera. The Input-Output analysis makes it possible to show how the parts of a system are affected by changes in other related parts. Socioeconomic impact measurement in each economy helps assess clearly and in detail all the social costs and benefits of a specific sector's expansion or reduction (Brinkman et al., 2019).

Nevertheless, two problems arise: first, small or newly developed sectors could not be present in official statistics, usually devised with a limited degree of disaggregation, and second, regional statistics in developing countries can be nonexistent, incomplete, obsolete, or incoherent with national statistics. Part of the task to achieve the goals of determining net job creation and net GHG emissions reduction consists of providing disaggregated, consistent, coherent, and updated regional Input-Output tables and models. We rest on Ferro et al. (2024), who developed such a first step, starting with regional contributions for each state - de Sá et al. (2014) for Rio Grande do Sul, dos Santos and Kureski (2022) for Paraná, and Haddad et al. (2018) for Santa Catarina - and conciliating information with the National Input-Output Brazil 2015 from IBGE (2018) and the Brazilian National Account information for 2018. We go beyond precedent contributions, estimating net instead of gross job creation and adding a computation of GHG emissions reduction to the analysis.

Regarding jobs and GHG emissions, input-output tables and models are expressed in monetary units, jobs are measured in persons, and GHG emissions are measured in MtCO2e.

Thus, the following step estimates satellite accounts to add to Input-Output tables, transforming conventional into hybrid Input-Output analysis.

There are three main approaches to regionalizing Input-Output Tables, depending on the statistics used to create them: 1) Direct techniques employing mainly surveys and specific data of a strictly sectoral nature (They are usually expensive and give rise to a time-consuming IOT construction process); 2) indirect or statistical techniques not requiring surveys and resting mainly on available secondary sources (Sometimes, they are inaccurate); 3) a hybrid approach being a mix of the two previous methods (Useful when the analysis points to a few sectors from which information can be obtained directly) (Rojo et al., 2020). Our contribution uses hybrid approaches, opening inexistent entries in the official Input-Output tables and adding satellite accounts to compute net jobs and GHG emissions.

The availability of an Input-Output Table, in turn, makes it possible to develop Social Accounting Matrices or SAMs.

2.5. Model

We conducted the impact study using an input-output model based on regional coefficients. This allowed us to achieve a more comprehensive and detailed analysis of the effects of a given policy directly on a sector and on other industries that might indirectly benefit from or be harmed by it.

The resolution is identical in regional and national models (Miller and Blair, 2009). According to the "open model," all final demand is exogenous: private consumption, public expenditure, investment, and exports. It means that increased household income because of greater output does not cause additional ("induced") demand due to greater consumption. The regional "open model" is as follows:

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

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 coefficients, 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).

In addition to the simple product multipliers resulting from the "open model" (type 1 multipliers), we also estimated job multipliers. Job multipliers are obtained by changing the measurement unit of the coefficients in matrix L^{rr}, using, for instance, the number of persons employed per product unit (Miller and Blair, 2009). They allow us to approach the problem from a different angle. Instead of concentrating on the monetary values of production increase, these employment multipliers compute the number of jobs the production increase generates.

3. <u>Scenarios and Findings</u>

Once the baseline is established in 2018, we consider a "shock" of partially replacing fossil fuel electricity with biogas and determine values for net job creation and net GHG emissions generation. The baseline is a GVP of 2018 USD 85 million in the South Region, employing 3,494 people (1,197 blue-collar workers and 2,297 white-collar workers). The state-level emissions are Paraná 102.8, Santa Catarina 40.8, and Rio Grande do Sul 89.6 MtCO2e.

Scenarios were devised based on moderate assumptions concerning the potential supply of substrates and the degrees of substitution achieved between fossil and biogas energy sources under different technologies. These technologies differ in costs per MW, employment potential, and energy efficiency. We assume zero emissions from the biogas production; however, the construction stage of the new plants yields positive emissions. The net effect on biogas emissions replacing electricity from conventional sources, including the plant construction stage, is negative.

We built scenarios to answer the following questions: What would happen with production, GHG emissions, and employment if 50 percent of potentially recoverable biomass in the Southern states of Brazil were employed for producing biogas? What would be the contribution of each of the Southern states of Brazil, and what would be the contribution of each type of biomass?

The scenarios consider that all the biogas produced will be used to produce electricity and sold wholesale. The introduction of electricity from biogas modifies electricity dispatch. The new order of supply dispatch leaves out thermal generation based on fossil fuels. It is assumed that the generation plants are located outside the states to take advantage of economies of scale in electricity production. The value of biogas production includes the cost of transporting the biomass.

Three scenarios are considered. They are based on three key factors related to biogas electricity production: 1) energy efficiency, 2) power plant technology, and 3) labor productivity (Table 4). According to existing reports (UNIDO, 2023) and market information, we have three alternative efficiency factors in kWh/m³ biogas: 1.51, 2.81, and 5.93. These are related to the investment costs in generation plants (including biodigesters) measured in millions of USD per MW: 1.5, 3.1, and 4.5. Finally, investment plants have an inverse relationship with labor productivity.

Table 4: Scenario design: technical parameters

Scenario	Energy Efficiency (kWh/m3 biogas)	Power plant technology (investment costs) in millions of USD per MW	Labor Productivity Direct (000 USD/job)
Low	1.51	1.5	100.3
Basis	2.81	3.1	149.4
High	5.93	4.5	292.8

Source: UNIDO and own elaboration.

Table 5 presents the results of the three scenarios that combine the investment and production shocks in the biogas-electricity chains.

Table 5: Aggregated results for the three scenarios

Scenario	Production (MM USD)		Emissions (MtCO2e)		Employment (jobs)	
	Direct	TOTAL	Direct	TOTAL	Direct	TOTAL
Investment Effect						
Low	60	109	0.015	0.030	1325	2154
Basis	235	423	0.058	0.118	5147	8365
High	712	1283	0.176	0.356	15612	25364
Operation Effect						
Low	589	1307	0.000	-0.474	8116	13942
Basis	589	1305	0.000	-1.222	4943	13361
High	589	1302	0.000	-2.951	767	11771
Total Effect						
Low	650	1416	0.015	-0.443	9441	16096
Basis	824	1729	0.058	-1.104	10090	21726
High	1301	2585	0.176	-2.595	16380	37136

Source: Own elaboration

Results refer to the average annual impacts (direct and total, including indirect) during the ten years of biogas sector investments and the production horizon we set. The direct effect of all variables only concerns the investment shock in biogas plants. In contrast, the production shock only leads to indirect impacts through substituting inputs for fossil fuels (thermal plant production) with biogas in power generation.

In the case of GHG emissions, we find that the direct effect of investment increases emissions -because buildings and installations should be constructed- but when electricity production starts switching from thermal to biogas sources (indirect effects), the net GHG emissions fall. For instance, in Table 5, if the basis scenario is considered, the investment effect is +0.118 MtCO2e, the operation effect is –1.222 MtCO2e, and the net or total effect is –1.104 MtCO2e.

The biogas sector producer opens the information of Table 5 for the basis scenario.

It is important to note that once the investment period is closed (since the 11th year, because time-to-build is assumed in 10 years), the reduction in GHG emissions will become even greater thanks to this substitution for environmentally cleaner technology for power generation.

Concerning job creation results across scenarios, it is important to highlight its nonlinearity. This is due to the trade-off effects of two underlying factors:

1. The change in the labor productivity due to the technology implemented in producing biogas-electricity, i.e., a technology that improves labor productivity, will create a lower number of jobs per unit of production and
2. The energy efficiency coefficient in the High scenario refers to a greater scale of electricity production, which leads to greater job creation.

Table 6: Basis Scenario (opened by biogas origin)

	Production (MM USD)		GHG Emissions (Mtco2e)		Employment (jobs)	
Sector	**Direct**	**TOTAL**	**Direct**	**TOTAL**	**Direct**	**TOTAL**
Investment effect by type of biogas						
Agriculture and cattle	76	138	0.019	0.038	1685	2764
Industrial	77	138	0.019	0.038	1652	2665
Solid waste and wastewater	82	148	0.020	0.041	1810	2936
TOTAL	235	423	0.058	0.118	5147	8365
Operation effect by type of biogas						
Agriculture and cattle	182	408	0.000	-0.197	1388	3467
Industrial	193	443	0.000	-0.457	1415	4403
Solid waste and wastewater	214	454	0.000	-0.568	2140	5492
TOTAL	589	1305	0.000	-1.222	4943	13361
Total (operation + investment) effect by type of biogas						
Agriculture and cattle	257	546	0.019	-0.158	3073	6231
Industrial	271	581	0.019	-0.419	3067	7067
Solid waste and wastewater	296	602	0.020	-0.527	3950	8428
TOTAL	824	1729	0.058	-1.104	10090	21726

Source: Own elaboration

Focusing on the Basis scenario, we can decompose the production (operation effect), GHG emission, and job creation impacts by biogas sectoral origin and state. Sectors with greater potential in biogas production and job creation are Agriculture, Solid Waste, and Wastewater, while those with higher performance in reducing GHG emissions are particularly the latter.

4. Conclusions

Our analysis is based on I-O methods and updated and homogeneous statistics. It addresses all complementary and substitution relationships among sectors to avoid partial reasoning in favor of or against specific sectors. We rest on empirical evidence and moderate assumptions on technical conversion factors.

However, caution is needed in advancing conclusions since nothing is that straightforward. The (partial) substitution of fossil fuels demands several adjustments in the infrastructure of electricity generation and public policies to help the market develop. This paper focused on the comprehensive socio-economic and environmental impact of developing the potential of biogas production for power generation; however, given the relevance of private investments in the biogas sector, it would be important to complement these results with a private cost-benefit analysis to provide an additional dimension of feasibility in the analysis of the biogas scenarios presented here.

The results help develop public policies (command and control—regulation—as well as incentive ones—taxes and subsidies—) to encourage changes in the energy matrix aimed at increasing net employment and decreasing net GHG emissions, based on evidence and avoiding partial (sectoral) arguments that can be distributive.

Jobs in biogas industries are sparse in the territory because of the nature of some biogas industries. Part of the production could be centralized in big cities, such as the one coming from solid waste processing, or from industries with great-scale economies, such as beer breweries and dairy products. Meanwhile, several small or medium-sized industries and agricultural enterprises can also produce biogas from their substrates. Thus, jobs will be generated in the whole territory of the states involved. GHG emissions reduction, in turn, will help the country achieve its goals facing international commitments to control global warming.

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