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ORIGINAL PAPER

Biomass availability assessment for biogas or methane production in Rio Grande do Sul, Brazil

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Abstract

Ensuring the environmental sustainability of energy production, including research and investment in renewable energy, can minimize the negative impact of fossil fuel use. According to the 2017 Brazilian national energy balance, biomass, a substrate for energy generation, represents approximately 23% of the national energy matrix. The state of Rio Grande do Sul currently imports 1.7 million metric tons of natural gas per day from Bolivia. Thus, the purpose of this study is to present the state's biomass, biogas and methane generation potential, considering agro-industry biomass residue (dairy and slaughterhouses), wine production, animal waste (cattle, poultry, sheep and horse), landfills and domestic wastewater treatment plants. The methodology consisted of three stages. First, a study was conducted to evaluate all possible sources of biomass in the state, along with relevant and reliable databases for each sector; second, on-site visits were carried out at the companies with the highest volumes of biomass to formalize and check the data. Finally, the theoretical biomass and biogas volumes from each source were calculated. The results indicate that Rio Grande do Sul can generate approximately 85 metric tons of biomass residue per year, around 9 million metric tons of biogas per day or 5 million metric tons of methane per day. Thus, the state can generate enough methane to supply all projected natural gas consumption in the coming years.

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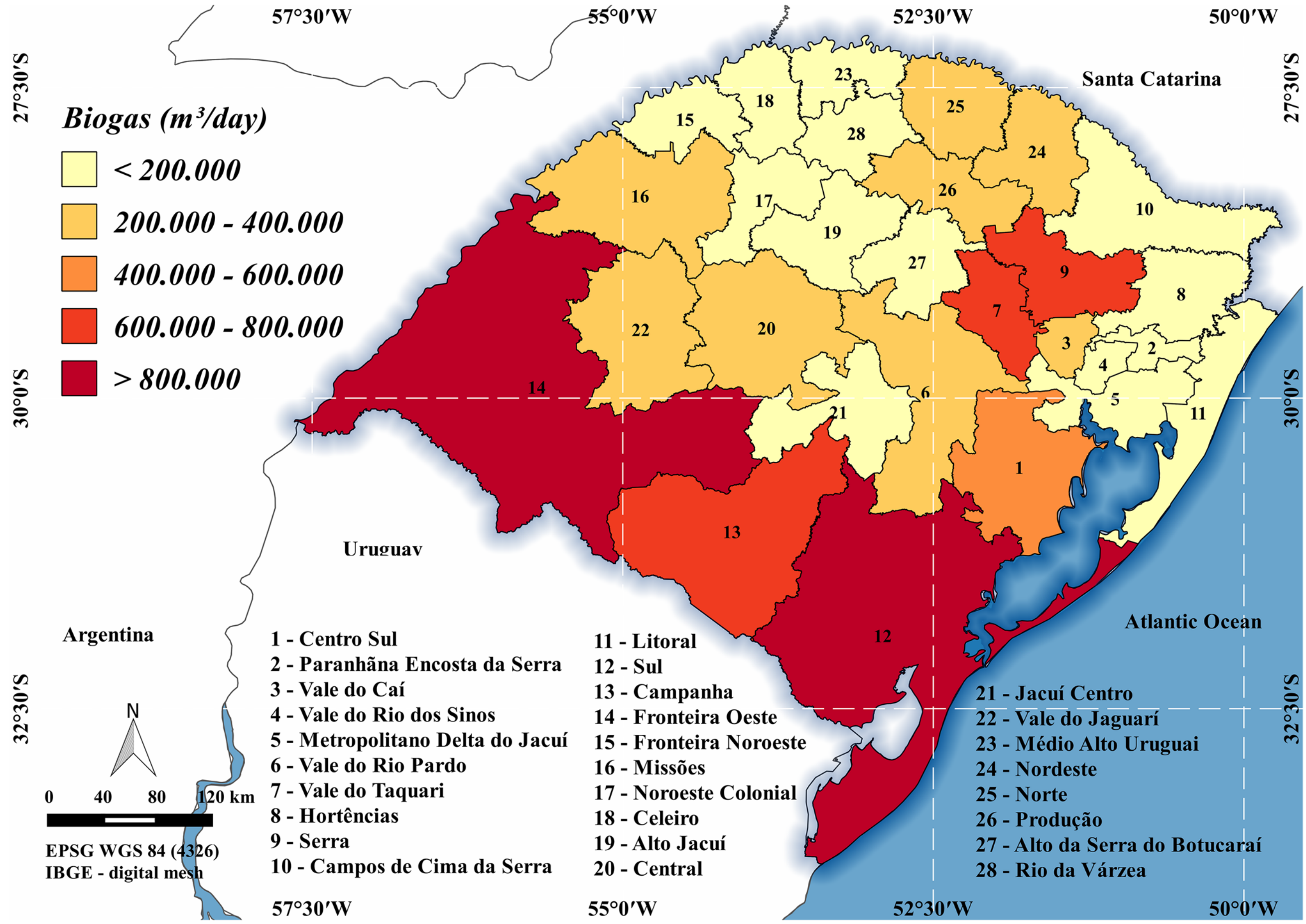
Graphic abstract



Keywords Organic waste · Farming · Agro-industries · Renewable energy · Sustainability

Acronyms and symbols

RS	Rio Grande do Sul
Mm³/day	Thousand cubic meters per day
MMm³/day	Million cubic meters per day
MMton/year	Million tons per year
COREDE	Regional Development Councils
IBGE	Brazilian Institute of Geography and Statistics
WWTP	Wastewater treatment plants
TS	Total solids
VS	Volatile solids

Introduction

It is essential to develop a balanced relationship between society and nature by creating social, economic and cultural conditions that favor compatibility between economic and environmental systems (Noorollahi et al. 2015). Energy is the primary element of a country's economic development (Gasol et al. 2011). One of the UN's goals for sustainable development (UN—Cúpula das Nações Unidas sobre o Desenvolvimento Sustentável 2015) involves access to energy sources, especially renewable, efficient and non-polluting ones, to ensure reliable, sustainable and modern access, as well as affordable energy prices, for all. This goal is characterized by interconnecting different levels of power: Although energy is fundamental to everyday life, it is also paramount to global industrial production, making it indispensable for society (Meyer et al. 2016).

Appeals to the environment, new legislation aimed at reducing fossil fuel consumption and public investment in clean energy production are increasing the share of renewable energy in the national and global energy matrix (Achinas et al. 2016). Because of this concern, many researchers around the world are seeking to assess the potential of renewable energy sources in their regions (Dinuccio et al. 2010; Bordelanne et al. 2011; Pick et al. 2012; Maghanaki et al. 2013;

Afazeli et al. 2014). In Brazil, incentives for biogas and methane generation from renewable sources are relatively recent, beginning in 2002 with the Federal Incentive Program for Alternative Energy Sources (Proinfa), the purpose of which was to diversify the national energy matrix and reduce carbon emissions. Although biogas has been in the schedule for many years in the country, this is the first study that regionally mapped the actual biogas or methane generation capacity of organic biomass from all 26 Brazilian states.

In this context, this study was developed in Rio Grande do Sul (RS), the southernmost state in Brazil. RS consists of 496 municipalities, divided into 28 Regional Development Councils (COREDE), which cover an area of 281,730 km^2 and a population of 11,207,274 inhabitants (IBGE - Instituto Brasileiro de Geografia e Estatistica 2010). Strategic planning of the RS energy sector is based on Decree 45.232 of 2007, which provides for the establishment of clean and competitive sources of energy based on the concept of sustainability. Incentives toward using biomass as an energy source emerged with Decree 48.530 (2011), which established a working group to identify partner institutions for developing biogas production. The National Petroleum Agency (ANP), through Resolution 8 (2015) and Resolution 685 (Brasil 2017), established guidelines for producing and using methane, a renewable fuel from biogas purification, as an analogue of fossil-based natural gas. Accordingly, RS enacted law 14.864 (2016), which established the State Biomethane Policy and the Gaucho Incentive Program for Biomethane Use and Generation (RS-GÁS) and which seeks to stimulate creation of a methane production chain in the state. In addition, the state's Energy Plan for 2016–2025 was created in early 2016 to guarantee regionalized energy supply.

According to the Brazilian Energy Balance (Empresa de Pesquisa Energética 2017), the country's total energy consumption in 2014 was 1.48x10^5 GWh (an increase of 2.18% over 2013), with transportation being the most significant sector (around 46%), followed by the industrial (21.44%), residential (13%), agricultural (8.22%), energy (5.45%), commercial (4.48%) and public sectors (1.56%). Based on this data, RS has been pursuing renewable energy sources. For example, a thermoelectric plant (biothermal) was built in the Minas do Leão municipal landfill in 2015 that generates energy from the biogas produced in the landfill (8.55 MW capacity), and three other plants are currently in development with an estimated production of 16 MW.

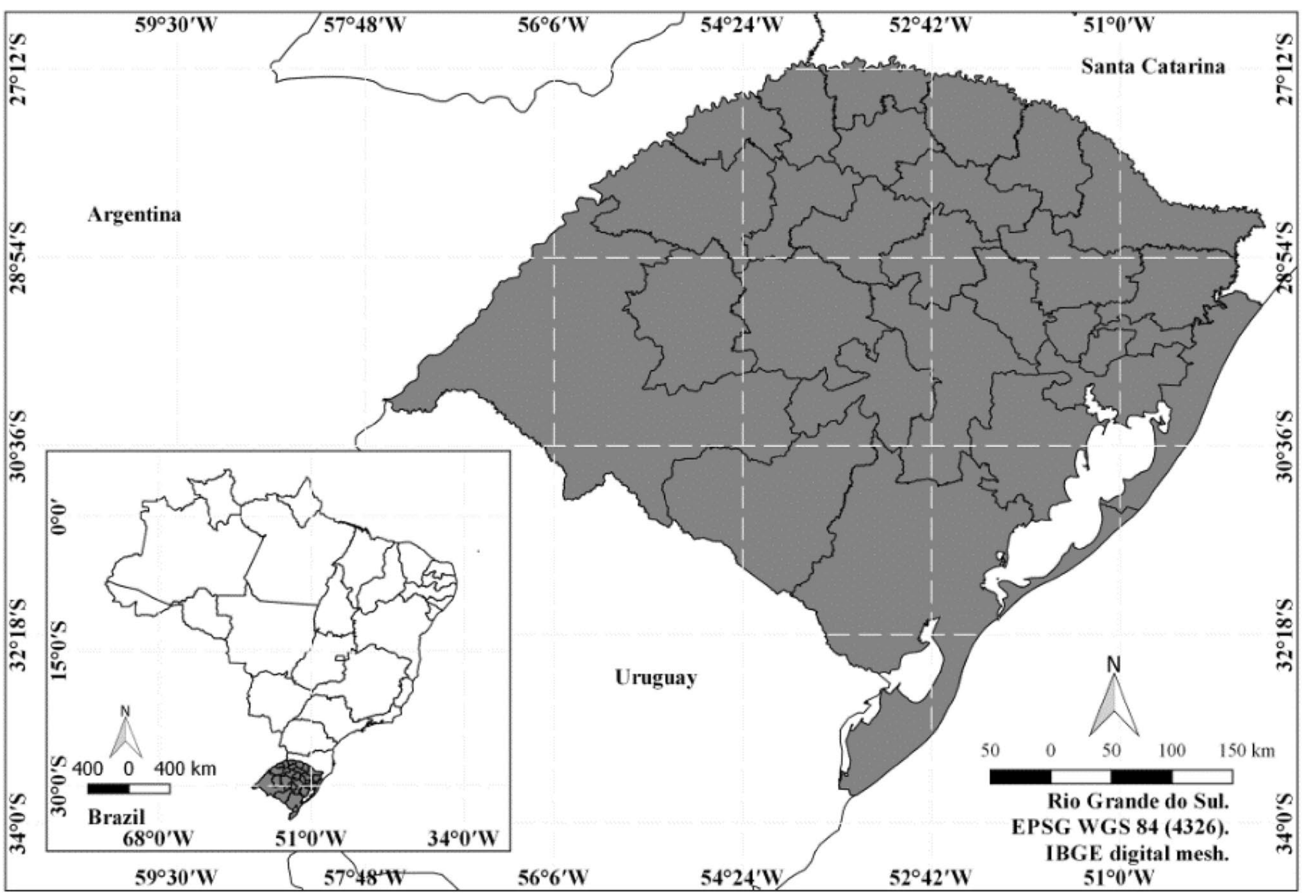


Fig. 1 Rio Grande do Sul subdivided into the 28 Regional Development Council territories

As described by Konrad et al. (2016), RS requires approximately 1.7 MMm^3/day of natural gas, which is distributed to gas stations and residential and commercial areas. The State Gas Company of Rio Grande do Sul (Sulgás) estimates that in the next 15 years, the mean daily consumption of natural gas will reach 5 MMm^3/day.

Due to the importance of diversifying the energy matrix at the local and global levels, with a focus on renewable energy sources, the objective of this case study is to present refined biogas and methane production data, spatially organized, of a region with great possibility to improve environmental characteristics by applying sustainable development techniques, especially to help new police for waste-to-energy economy and serve as a basis for regional clean energy strategies and can facilitate future research and investments in the bioenergy sector.

Methodology

Experimental area

The residual biomass available in RS (Fig. 1) was quantified individually for each of the 28 Regional Development Council (COREDE) territories based on: livestock production, agro-industry, wine production, wastewater treatment plants (WWTP) and landfills (Table 1). It should be pointed out that the types of biomass analyzed in this study were preselected and that several other available sources of organic biomass, such as food companies, were not included in the analysis.

Database

The herd size of each animal type was collected from the Brazilian Institute of Geography and Statistics animal husbandry production database (IBGE 2010). To simplify the models, were used only adult animals to quantify waste.

The annual livestock biomass was calculated according to Eq. 1.

$$\text{Yearly biomass}\left(\frac{\text{ton}}{\text{year}}\right): 365\text{day} \times \text{no animals} \times \left(\frac{\text{Manure in kg /animal /day}}{1.000}\right) \tag{1}$$

The biomass output of the non-participating companies (23%) was estimated directly by linear regressions based

Table 1 Residual biomass evaluated categorized

Sector	Source	Type of biomass	Total number of animals/companies evaluated
Livestock	Animal manure	Cattle	14,059,100
		Swine	6,310,790
		Poultry	148,501,850
		Horse	536,610
		Sheep	4,253,696
Agro-industry	Cattle slaughter, pork and poultry and dairy products.	Blood	240
		Rumen	
		bowels	
		WWTP sludge	
		Waste fat	
		Condemned milk	
Wine production		Bagasse	165
		Stem	
		Must	
		Sludge	
WWTP		Anaerobic and aerobic sludges	60
Landfills		Urban solid waste	31

Based on agro-industrial data collected in a previous survey, 496 companies were identified as having a high potential for generating residual biomass. A sample of 228 companies was selected to measure biomass output: For 50% of the companies, data were collected in on-site visits and interviews with managers; for 27%, data were collected through telephone calls or e-mail; the other 23% showed no interest in contributing to the study

Table 2 Residual biomass generated in agro-industry and wine production

	Poultry slaughter	Cattle slaughter	Pig slaughter	Dairy products[a]	Wineries[a]
Condemned milk	–	–	–	0.0005%	–
Sludge	0.25 kg/animal	148 kg/animal	22 kg animal	2%	23 L/m^3
Vegetable residue (must, bagasse and stems)	–	–	–	–	0.09 ton/m^3
Waste fat	0.5 kg/animal	85 kg/animal	15 kg animal	–	–
Rumen	–	26 kg/animal	–	–	–
Blood	0.110 L/animal	22 L/animal	4.5 L animal	–	–

[a]Estimated biomass based on 2016 data collected from milk and wine processing

Table 3 Residual biomass production according to animal category

Animal category	Manure (kg/animal)	Yield methane[e] (%)	Yield biogas[e] (m^3/ton VS)
Poultry	0.15[a]	55	550
Cattle	10.00[a]	55	450
Horse	10.00[b]	55	480
Sheep	1.50[c]	55	450
Swine	7.00[d]	60	500

VS volatile solids

[a]Estimated poultry and cattle manure based on Kunz and Oliveira (2006)

[b]Estimated horse manure based on Hadin and Eriksson (2016)

[c]Estimated sheep manure based on (Mosquera et al. 2012)

[d]Estimated pig manure based on the mean values presented by (Tavares et al. 2014; Guerini Filho et al. 2015)

[e]*Kuratorium für Technik und Bauwesen in der Landwirtschaft eV* (KTBL 2017)

on data provided by the Ministry of Agriculture, Livestock and Supply (MAPA), and the processing capacity specified in the environmental license issued by the State Foundation for Environmental Protection (FEPAM) (Konrad et al. 2016).

Only sanitary landfills with active environmental licenses in 2017 were considered. Regarding domestic sewage treatment plants, operating flows were estimated from data available in the National Sanitation Information System (SNIS) (2014) as a percentage of sewage collected and treated and from field data. A value of 0.88 kg of wet sludge per m^3 of treated effluent was used to quantify sludge from effluent treatment stations (Ginestet and Camacho 2007).

Estimating biogas production

Methodology developed by the *Kuratorium für Technik und Bauwesen in der Landwirtschaft eV* was adapted to estimate biogas production. This methodology considers total solids

Table 4 Total solids and volatile solids from the evaluated sources of biomass

Categories	Residual biomass	TS (%)[a]	VS (%)
Animal manure	Poultry	18	63
	Cattle	11	56
	Horse	13	83
	Sheep	33	76
	Swine	3,5	66
Dairy	Condemned milk	11	92
	Sludge	4,5	85
Cattle slaughter	Sludge	12	82
	Rumen	10	86
	Blood	12	94
	Bowels	65	98
Poultry slaughter	Sludge	7	97
	Blood	12	94
	Bowels	40	96
Pig slaughter	Sludge	5	88
	Blood	12	94
	Bowels	28	95
Wineries	Sludge	1,4	55
	Vegetable waste	19	79
Landfills	Urban solid waste	30	45
WWTP	Sludges	4	65

TS total solids, *VS* volatile solids and *FS* fixed solids

[a]$TS_{\%} = VS_{x\%} + FS_{y\%}$

(TS), volatile solids (VS) and biogas and methane yield per ton of VS, as outlined in Eqs. 2–5:

$$\text{Yearly total solids}\left(\frac{\text{ton}}{\text{year}}\right):\text{biomass}\left(\frac{\text{ton}}{\text{year}}\right)\times \text{TS}(\%) \quad (2)$$

$$\text{Yearly volatile solids}\left(\frac{\text{ton}}{\text{year}}\right):\text{TS}\left(\frac{\text{ton}}{\text{year}}\right)\times \text{VS}(\%\,) \quad (3)$$

$$\text{Biogas day}\left(\frac{m^3}{\text{day}}\right):\frac{\text{VS}\left(\frac{\text{ton}}{\text{year}}\right)\times \text{yield.biogas}\left(\frac{m^3}{\text{ton VS}}\right)}{365} \tag{4}$$

$$\text{Methane day}\left(\frac{m^3}{\text{day}}\right):\text{biogas day}\times \text{yield methane} \tag{5}$$

To determine the total, fixed and volatile solids, gravimetric method 2540B (APHA - American Public Health Association 2005) was used, which consists of drying a sample (± 30 ml) of each substrate in a drying oven at 105 °C for 24 h and, after, the sample has cooled to room temperature; it is weighed to obtain the total solids value. Afterward, the sample is heated to 550 °C for 4 h and weighed after cooling to obtain the volatile solids value. All analyses were performed at the UNIVATES Bioreactor Laboratory.

Results and discussion

Biomass characteristics

Associations were found between the residual biomass generated by the five analyzed sources. Table 2 shows the values obtained from laboratory analysis of agro-industrial and wine production biomass.

As shown in Table 3, the biomass generated from livestock production was estimated according to the amount of manure generated, the biogas yield and the mean concentration of methane for each animal type based on data in the literature.

Solids are one of the most important parameters in analyzing anaerobic biodigestion processes, since they can be used to determine the bioavailability of organic material susceptible to volatilization (El-Mashad and Zhang 2010;

Table 5 Estimated total biomass generation in Rio Grande do Sul

COREDE	Agro-industry[a]	Animal manure (ton/year)				
		Cattle	Swine	Poultry	Horse	Sheep
Médio Alto Uruguai	79,016	910,737	1,201,098	136,415	10,508	5497
Norte	62,930	1,046,973	2,354,857	574,120	13,260	8359
Celeiro	48,221	765,420	1,095,303	62,367	10,713	3339
Rio da Várzea	96,856	576,408	601,130	41,851	8121	7462
Nordeste	55,066	907,058	429,912	906,246	18,889	11,442
Fronteira Noroeste	16,083	1,146,575	1,282,909	34,032	13,078	6072
Missões	198,795	2,850,172	728,057	33,970	60,356	92,495
Produção	156,468	628,074	809,294	1,150,894	18,776	13,063
Campos de Cima da Serra	19,958	1,376,353	146,708	75,361	40,621	16,415
Noroeste Colonial	22,094	700,705	191,196	16,617	16,451	11,224
Alto Jacuí	22,857	597,600	390,596	28,588	16,111	14,797
Fronteira Oeste	106,862	12,362,616	234,168	20,189	480,026	915,632
Serra	748,536	908,580	1,421,640	1,870,700	33,514	14,171
Alto da Serra do Botucaraí	4113	808,771	199,862	168,168	27,696	11,538
Central	175,043	2,394,991	167,820	28,117	82,541	69,023
Hortênsias	119,694	814,008	40,507	20,204	27,014	8240
Vale do Taquari	345,295	912,259	2,554,512	1,965,662	20,564	9956
Vale do Jaguari	8430	3,041,202	50,070	11,191	74,748	105,279
Vale do Rio Pardo	84,282	2,068,612	567,317	91,335	76,216	66,276
Litoral	55,906	817,169	51,680	6,873	43,424	18,461
Vale do Caí	209,852	257,340	973,542	601,584	7450	3529
Paranhana-Encosta da Serra	52,671	213,850	17,609	93,025	10,012	2030
Jacuí-Centro	5554	1,424,099	93,183	31,256	55,049	52,663
Vale do Rio dos Sinos	414,411	156,742	33,427	10,464	42,252	6,788
Metropolitano Delta do Jacuí	1,181,050	912,172	50,017	17,289	91,301	25,747
Centro-Sul	1,285,621	1,258,148	161,083	24,517	81,081	37,443
Sul	119,698	6,209,924	223,435	103,223	339,457	461,277
Campanha	99,685	5,255,887	56,202	12,787	239,579	330,996

COREDE Regional Development Council

[a]agro-industrial biomass: the total biomass generated by wineries, landfills and WWTP

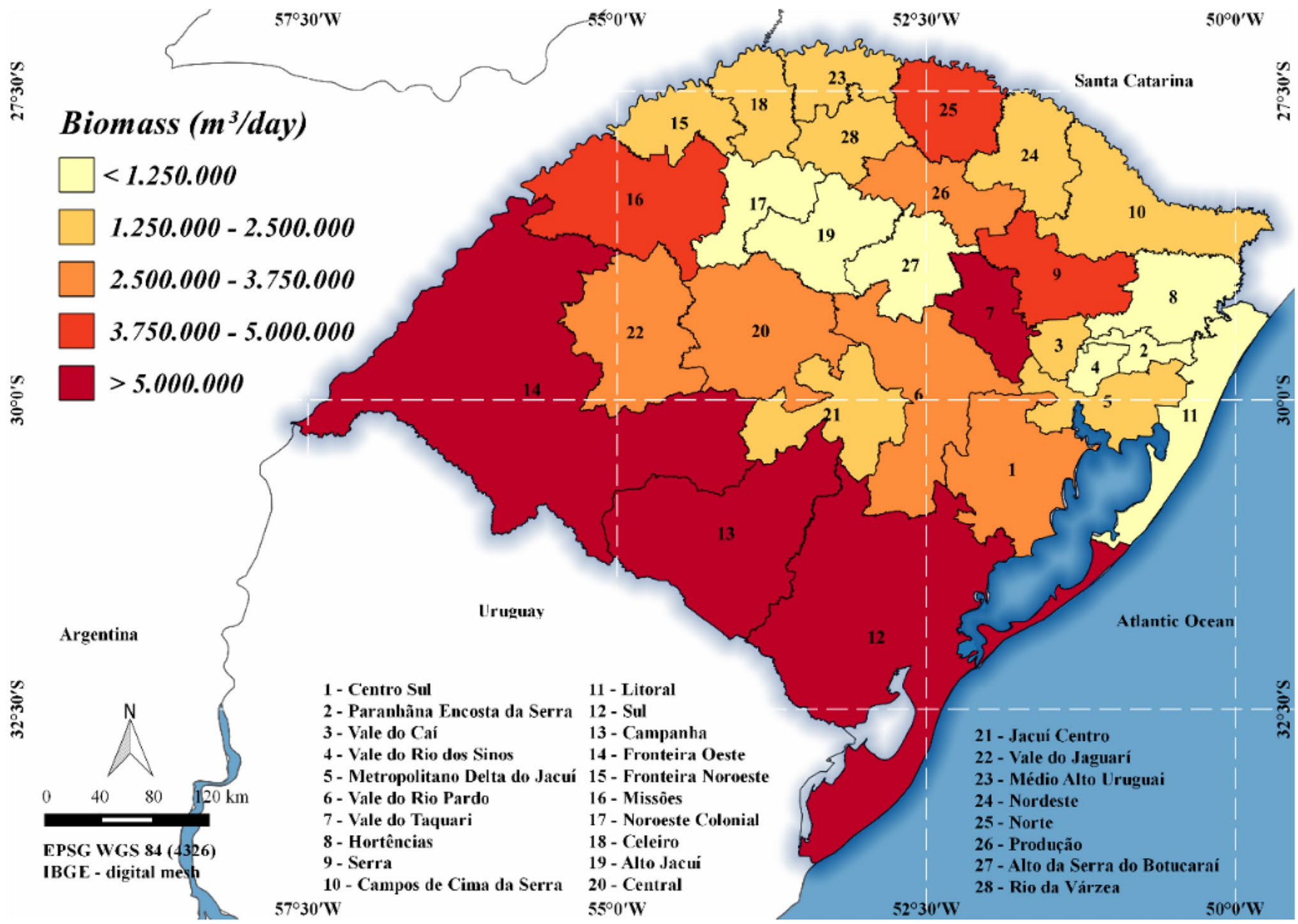


Fig. 2 Estimated biomass generation in Rio Grande do Sul

Pakarinen et al. 2011; Hasan et al. 2018). Table 4 shows the total and volatile solids for each category of biomass.

Biomass and biogas estimation

To better understand the data, the results obtained were evaluated considering different scenarios, which will be detailed as follows:

Scenario I

Based on the result of the surveys, the total biomass generated in the state is approximately 85 million tons/year. The regions with the highest percentages of biomass are the Western (16%) and Southern borders (8.7%), Campanha (7%), the Vale do Taquari (7%) and the Serra (6%). The most representative biomass sources are bovine and swine manure, (59% and 19% of the total, respectively). Table 5 shows the estimated total biomass for each category in each region.

Figure 2 shows a map of the estimated biomass generated in RS in tons per year. This analysis, which does not take logistic, seasonal, legislative or production system factors into consideration, indicates that residual biomass from livestock is the largest single sector, of which cattle, swine and poultry are the most representative sources, representing approximately 88% of the total biomass produced in the state. The remaining biomass is from the agro-industrial sector (dairy and slaughter) (2.32%), landfills (2.71%),

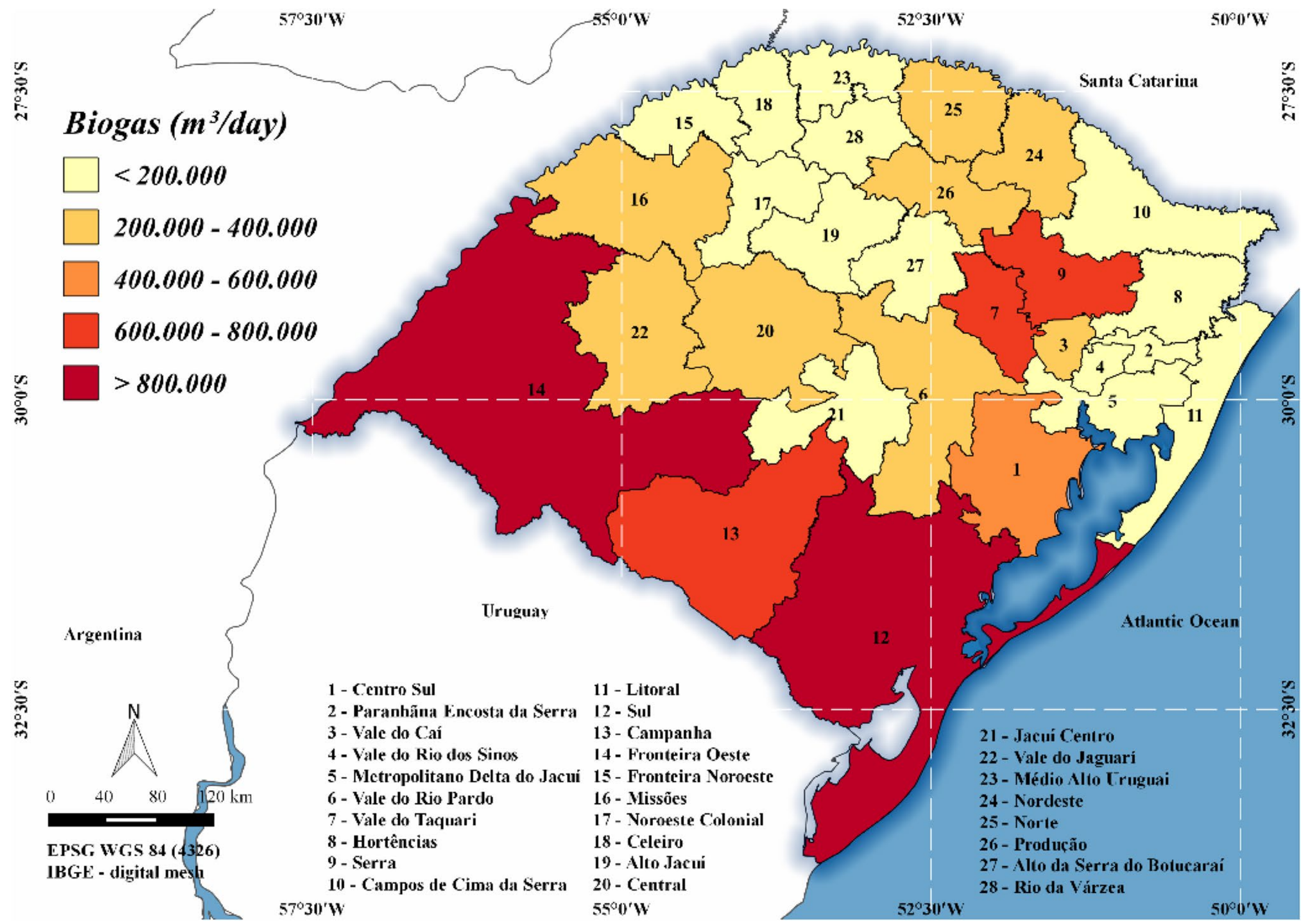


Fig. 3 Estimated total biogas generation in Rio Grande do Sul

WWTP (1.40%) and wine production (approximately 0.34%).

The state biogas potential was estimated at approximately 9 MMm^3/day. Bovine, poultry and porcine wastes have the greatest potential for biomass generation, with percentages of approximately 52%, 15% and 6%, respectively. Approximately 7% of the total estimated biogas is generated by the agro-industrial sector. The most representative regions in this analysis are the Western and Southern borders, Campanha, Serra and the Vale do Taquari, which are responsible for approximately 50% of production. According to Figs. 3 and 4, the regions with the greatest potential for biogas or methane generation are in the south, due to the concentration of large cattle farms in the Pampa biome.

Scenario II

Considering that approximately 80% of the cattle, sheep and horses in the state are raised under free range conditions, and their manure cannot be used for biogas production, since collecting the material is unfeasible. However, many farms are migrating to an intensive production system, although the percentage is still low (< 20%) (IBGE 2016). To determine the regions with the greatest potential for biogas production, we considered only biomass that could be collected and used immediately, such as swine and poultry agro-industrial waste and organic residues from wine production.

Figures 5 and 6 show that regions such as Serra (536 Mm^3/day of biogas and 321 Mm^3/day of methane), Vale do Taquari (525 Mm^3/day of biogas and 315 Mm^3/day

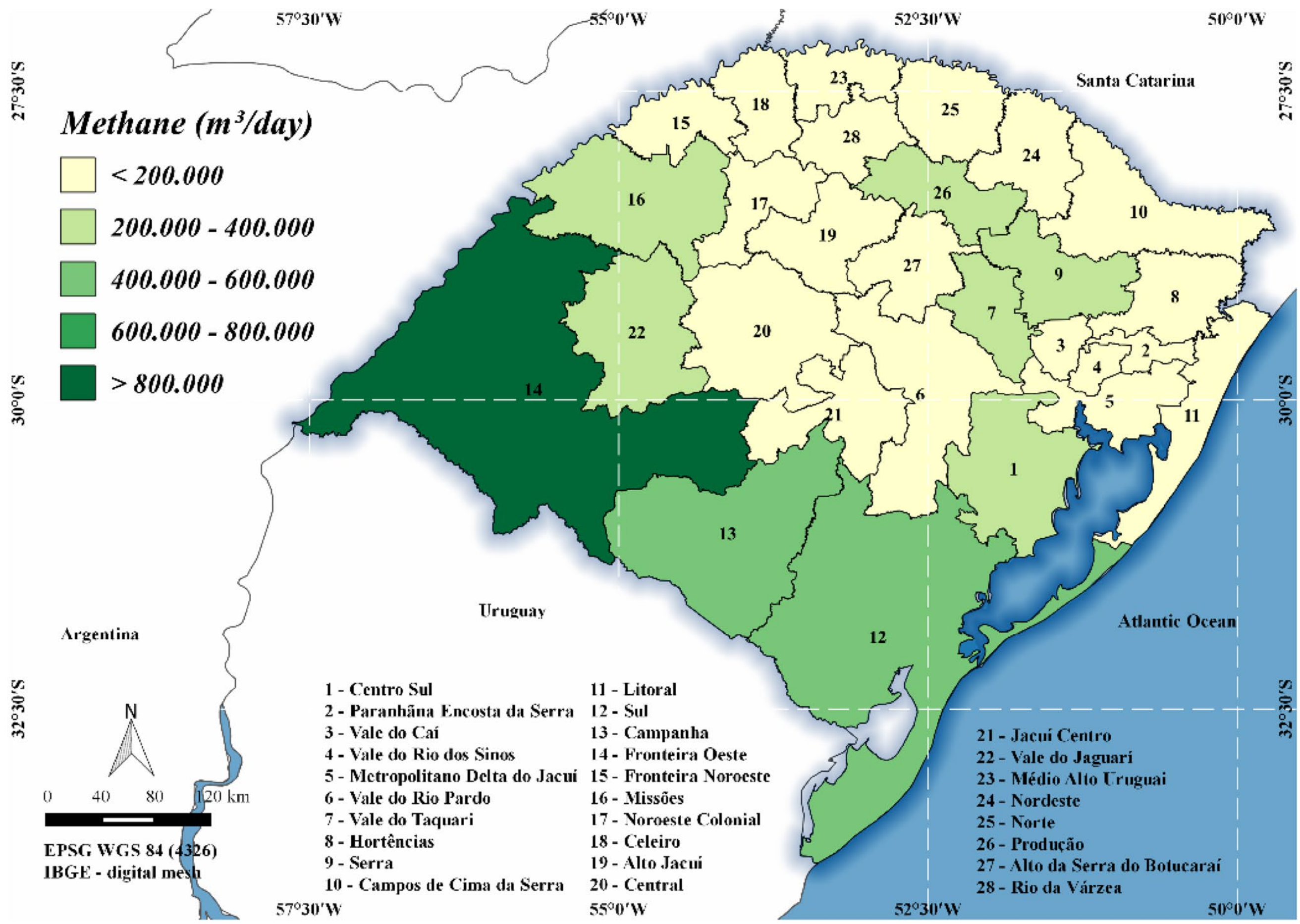


Fig. 4 Estimated total methane generation in Rio Grande do Sul

of (269 Mm^3/day of biogas and 161 Mm^3/day of methane), and Vale do Caí (210 Mm^3/day of biogas and 126 Mm^3/day of methane) have the greatest potential for generating biogas and methane.

The total annual availability biomass is approximately 27 million tons, which can generate about 2.6 MMm/day of biogas and 1.6 MMm/day of methane. Among the evaluated sources of biogas generation, poultry manure represents 52.40% of the total, which is produced mainly in the Serra and Vale do Taquari regions (mean 530 Mm^3/day).

The second most significant potential source for biogas, at approximately 24%, is the agro-industrial sector, which includes residual biomass from dairy products and livestock slaughter. Again, the main regions are Serra and Vale do Taquari (mean 103 Mm^3/day). Biogas production from pig manure, 21% of the calculated total, is also concentrated in these two regions, which could yield an estimated 88 Mm^3/day and 49 Mm^3/day in the Vale do Taquari and Serra regions, respectively. The wine production sector could generate approximately 60 Mm^3/day of biogas from organic residues.

Scenario III

Poultry waste, swine manure and biomass from agro-industries and wineries were potential sources of biogas. Only waste from egg-laying hens was considered in this scenario due to better collection logistics, less seasonality and its being pure waste, i.e., not mixed with bedding. Another decisive factor in this decision was the competition for bedding

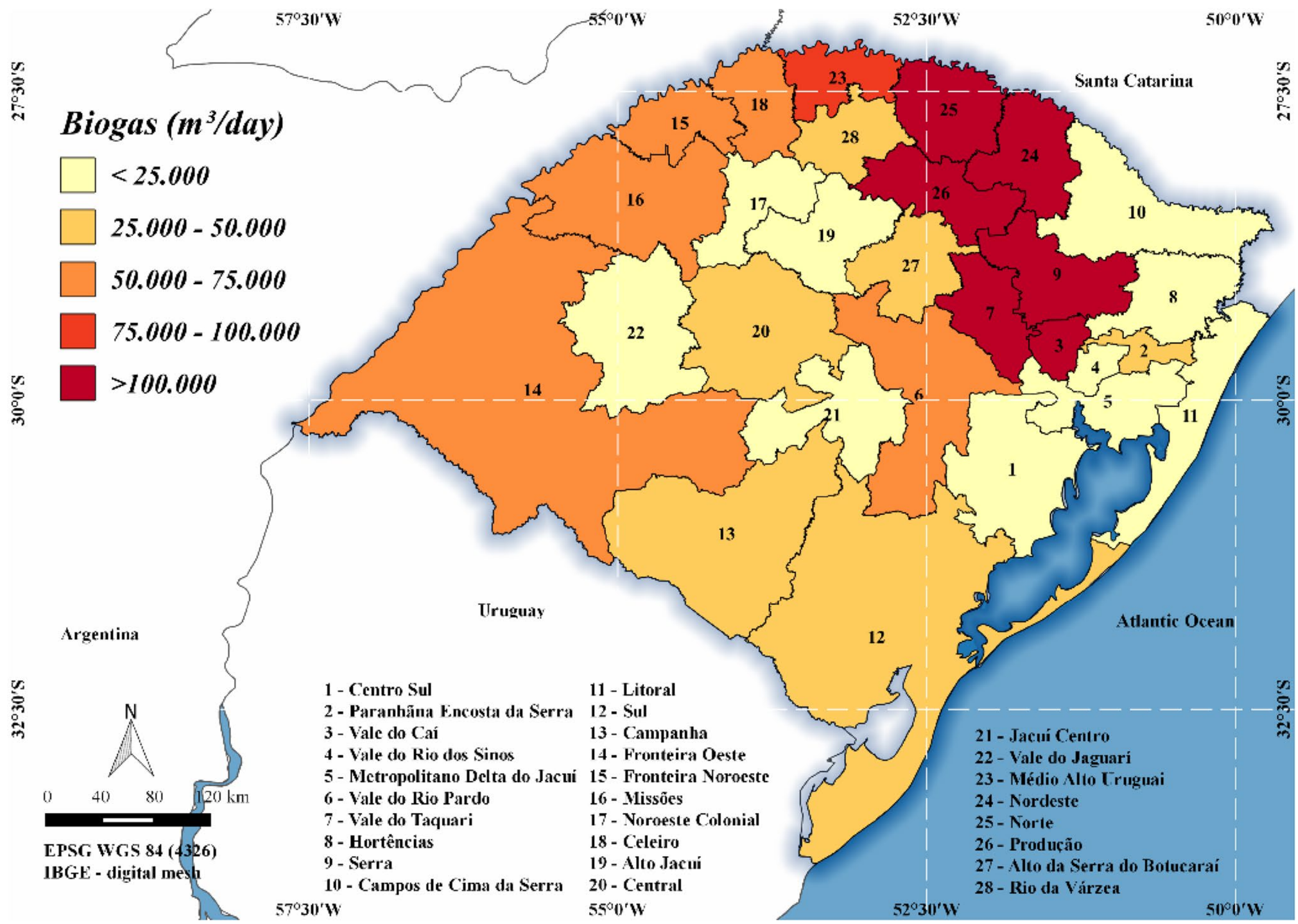


Fig. 5 Estimated biogas generation in scenario II

waste for use as an organic biofertilizer, which would reduce the quantity available for anaerobic biodigestors (de Silva et al. 2012).

Figures 7 and 8 show maps of potential biogas and methane generation. Serra and Vale do Taquari could produce 224 Mm^3 and 197 Mm^3 of biogas, and 134 Mm^3 and 118 Mm^3 of methane, respectively, followed by the Vale do Caí (126 Mm^3/day of biogas and 76 Mm^3/day of methane) and a production of 72 Mm^3/day of biogas and 43 Mm^3/day of methane.

Of the biomass sources for biogas generation, it was estimated that the agro-industrial sector and pig waste could produce approximately 49% and 43% of the total, respectively, and once again these sources were concentrated in the Serra and Vale do Taquari regions. Biogas production from poultry waste represents approximately 2.90% of the calculated amount.

Mapping indicated that the spatial distribution of biomass in RS was heterogeneous due to the range of regional economic activities. In the southern and southwestern regions, there is a greater availability of biogas from cattle manure, while in the northeast region (Produção, Serra, Vale do Taquari and Vale do Caí), biogas potential comes from the residual biomass of agro-industries, as well as swine and poultry waste. Moreover, in the central and metropolitan area of Porto Alegre, biomass is predominantly derived from domestic effluents and sanitary landfills.

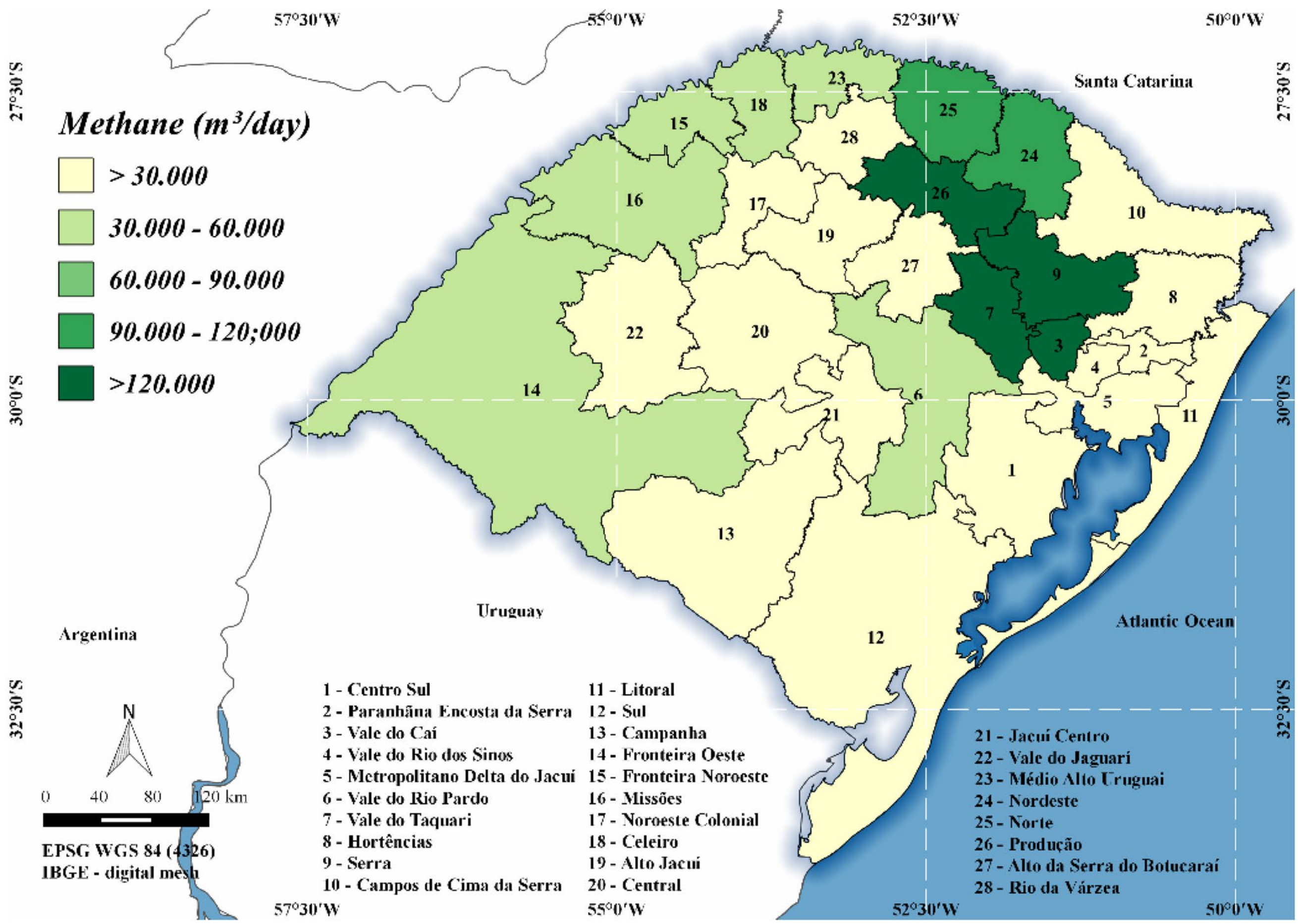


Fig. 6 Estimated methane generation in scenario II

Conclusion

In Latin America, more specific in Brazilian South, this is the first detailed study that carried out a regional mapping of residual biomass availability that could be used as substrate for energy production (by anaerobic digestion). This study presented with distinction the geospatial distribution of energy generation capacity by specific biomasses residuals in Rio Grande do Sul, having as main differential the measurement of the data through the research done in loco with the companies. It was observed that some forms of biomass are easily accessible, available statewide and are suitable for direct use in anaerobic digestion. Compared to other energy sources, biogas has a relatively low cost, can be used for a variety of purposes and different types of biomass can be treated simultaneously in a decentralized manner.

If full advantage was taken of all methane generation sources, not to mention the other possible sources of organic biomass, RS could provide for its own projected natural gas requirements for the next 15 years, freeing it from dependency on imported Bolivian gas. In this bias, it was estimated that the RS presents the capacity to produce 9 MMm^3/day of biogas or 5 MMm^3/day of methane.

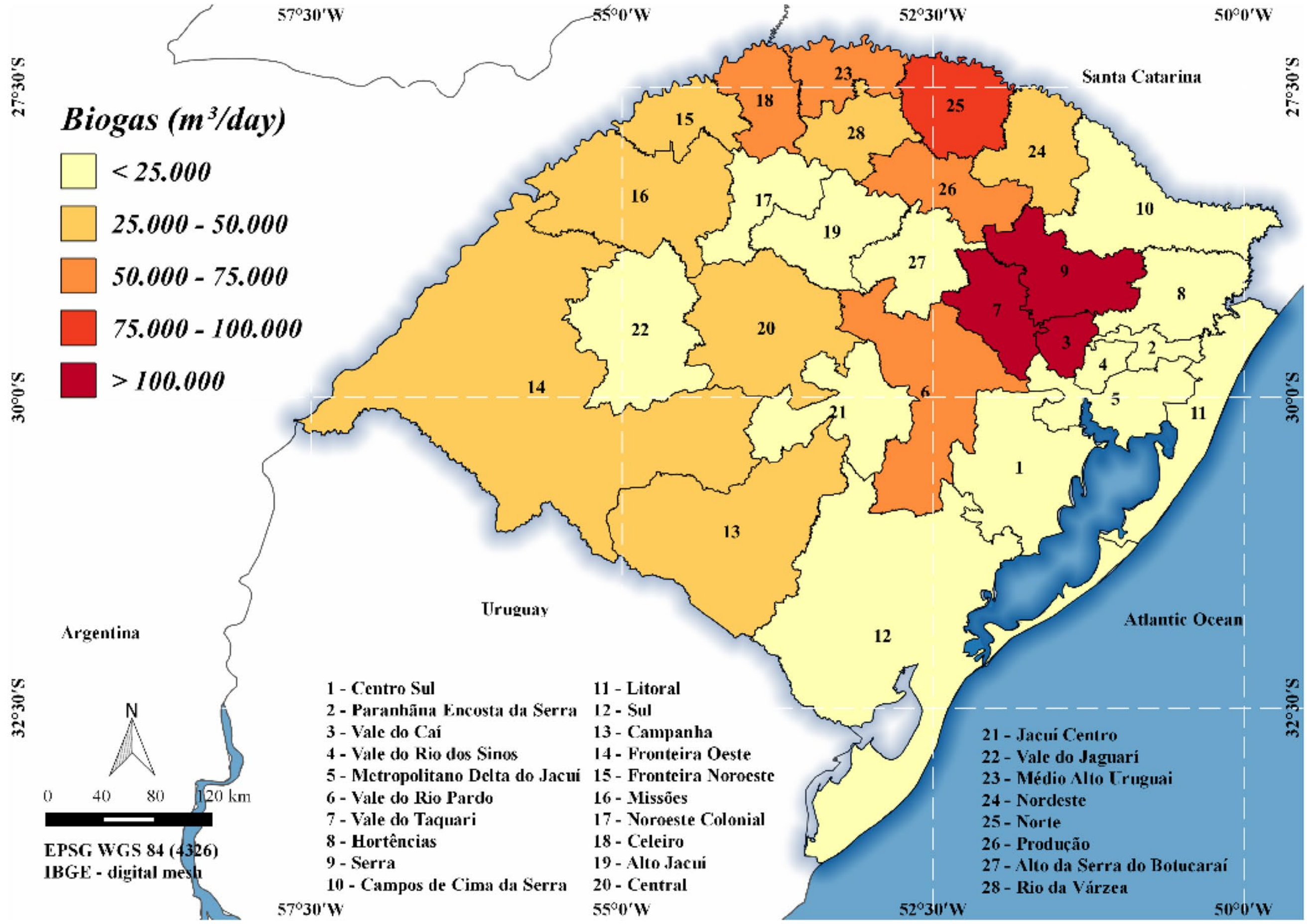


Fig. 7 Estimated biogas generation in scenario III

Biogas and methane from agricultural and livestock waste are renewable energy sources and viable replacements for fossil fuels in the current bioenergy scenario. In RS, there is a great availability of biomass for energy generation through anaerobic digestion. It can be concluded that in light of the current natural gas consumption (1.7 MMm^3/day), RS can become self-sufficient through biomass, which can be used immediately or it would be possible to produce 2.6 MMm^3 day^{-1} of biogas.

This results of this study can be used for energy and territorial planning to encourage the use of biogas and methane as a source of renewable energy throughout Brazil and mitigate/reduce the negative consequences of direct waste disposal in the soil, air and water and can contribute to future

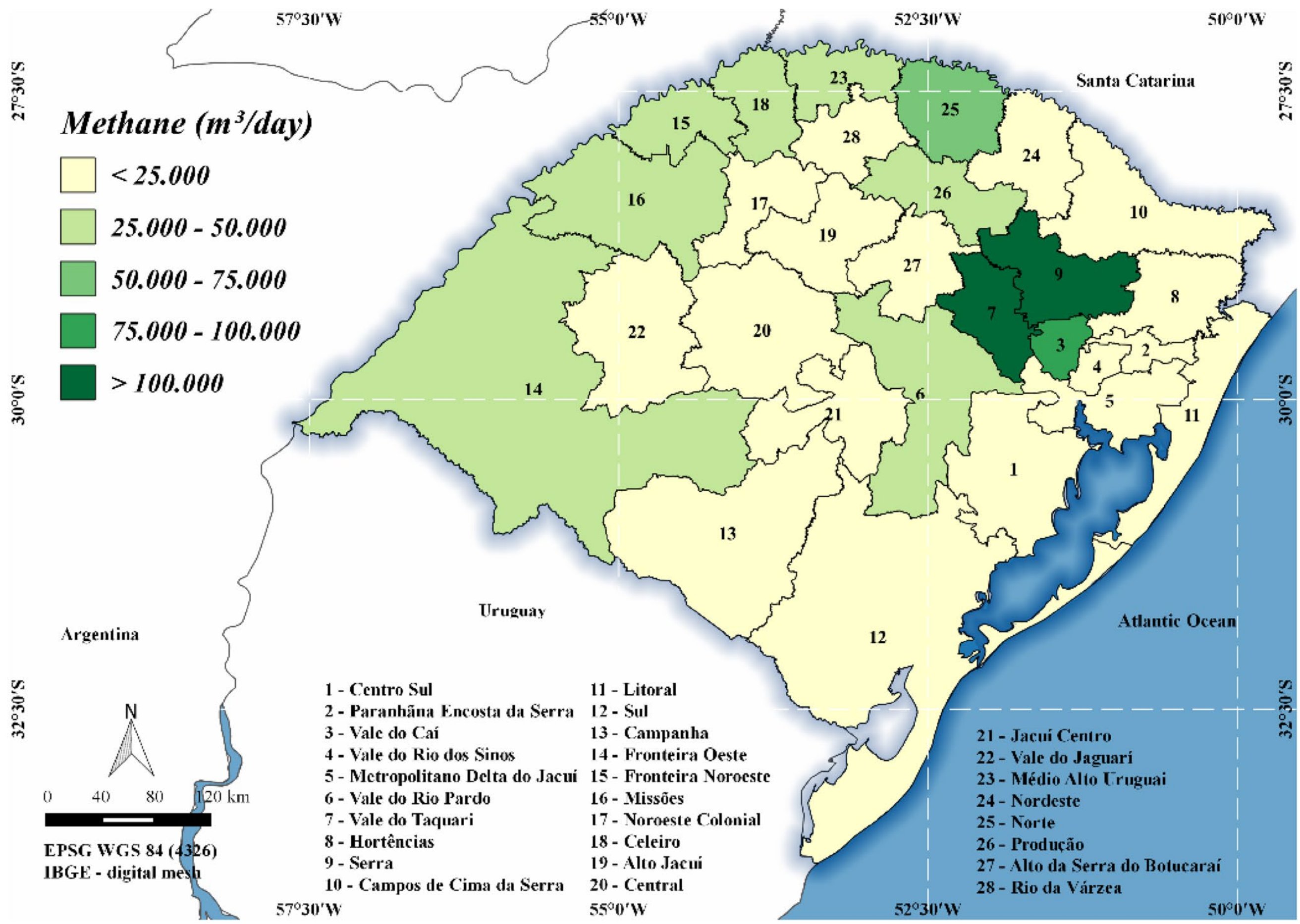


Fig. 8 Estimated methane generation in scenario III

studies and public policies that stimulate the production of biogas as a source of energy.

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