ANALYSIS OF THE AVAILABILITY OF URBAN SOLID WASTE AND BIOMASS IN SOUTHERN SANTA CATARINA AIMING AT ENERGY RECOVERY

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ABSTRACT

Alternative treatments to urban solid waste (USW) landfill and its integration with biomass can generate social, economic, and environmental benefits beyond contributing to the just energy transition in the Carboniferous Region of Santa Catarina State (Brazil). In this paper, were collected and analyzed data on generation, quantity processed, and current USW treatment practices, as well as rice and forest biomass, aiming to identify the potential for application in the development of USW-derived fuel and biomass that can be used in the energy and industrial markets. In 2020, 236,272.2 t of USW were produced by the forty municipalities considered, with 50% concentrated in just five of these. With only three landfill sites in this region, many municipalities dispose of their USW at a distant location, which increases the overall cost of waste management for the municipalities. The total forest biomass handled in 2019 was 2,135,704.31 tons, and rice husk and straw (2020/2021 harvest) were 999,750.00 tons. Based on this amount and the analysis of the points of concentration of these materials, alternative treatments are being studied with a focus on adding value to the waste chain and advances in the development of the waste management sector in Santa Catarina and in Brazil.

Keywords: Urban solid waste; Biomass; Waste energy recovery; Just Energy Transition.

NOMENCLATURE

HWA: household waste;
IMA: abbreviation for Instituto do Meio Ambiente, environmental control agency of Santa Catarina;
PERS: abbreviation for Plano Estadual de Resíduos Sólidos, state plan for solid waste;
PPW: portions of public waste;
SNIS: National Sanitation Information System;
TEJ: abbreviation for Transição Energética Justa, just energy transition;
USW: urban solid waste.

INTRODUCTION

Waste management and challenges

The urban solid waste (USW) management is a current global challenge, both for disposal and in relation to the generation of effluents. Studies in these areas are important at any level of the production chain, especially when energy transformation is related to waste reduction and less environmental degradation.

The literature is clear pointing out that almost all cities around the globe have problems related to their waste, with great aggravation due to population growth and improvement in living standards (Chen et al., 2020; Gouveia, 2012; Kalinci; Dincer, 2018). Moreover, the waste management has become a challenge, both economically and environmentally. The estimated value of the amount of waste generated per year in the world is around 2.2 billion tons (Infiesta et al., 2019).

Brazil is a developing country, with a relatively low average income, but, in terms of urban solid waste generation (per capita), it is on a par with developed countries (cetrulo et al., 2018). It is the fifth largest country in the world based on geographical features and the sixth largest in the world in economy. Politically it is divided into 27 states, with more than 5,000 municipalities and a population estimated by the Brazilian Institute of Geography and Statistics (IBGE) at around 212 million inhabitants in the year 2020. Comparing its population projection, it is estimated that each inhabitant is responsible for generating about 1 kg of urban solid waste daily (Abrelpe, 2019), which is equivalent to assume that about more than 200 thousand tons of USW are generated per day in the country (approximately 73 million in one year). In this way, currently one of the biggest challenges of Brazilian cities is to properly manage this solid waste collected daily by the country (Besen; Fracalanza, 2016). The coordination of the disposal of USW in Brazil is the responsibility of the public authorities. According to Guerrini et al. (2017), they have several options to improve the efficiency of solid waste management, amongst them, technological innovations, people training and the development of a control system for the effective and efficient incorporation of processes. The current destination for most of the USW generated in Brazil are sanitary landfills, where waste is degraded over many years, depending on its composition, presenting environmental and long-term risks, to be left for future generations. Regarding the methane (CH_4) emission from landfills, which is 25 times more harmful than carbon dioxide (CO_2) for global warming (Gug; Cacciola; Sobkowicz, 2015), the search for alternatives to this type of destination has increased.

Related to the Santa Catarina State, it can be highlighted in the national scenario when it comes to USW treatment, being a pioneer in the closure of dumps in 2014. The use and conversion of residues in this State landfills can be an excellent development alternative for the sector. In 2018, the southern of Santa Catarina had three large landfills registered in the State Plan for Solid Waste (Pers, 2018), being responsible for centralizing the USW around their location (neighboring cities).

The European Union's policy and legislation on waste management has strongly encouraged the circular economy and the preservation of the environment. It is expected that the national policy will be stimulated by these managements, with new actions to support the reuse of waste, especially for energy generation. In this way, the implementation of reuse policies is both economically and environmentally favorable. As an example of these actions, one can cite the specific norm for the analysis of the requirements for the use of USW for energy purposes, available in Brazil since February 2020. The standard aims to promote the safe and sustainable use of USW, increasing the reliability of energy recovery practices (ABNT, 2020).

It is expected that the Brazilian national policy will be stimulated by these governments, with new actions to support the reuse of residues, especially for energy generation. This way, the implantation of utilization policies is both economically and environmentally favorable.

Biomass as residue and recoveries

Another point related to the generation of solid waste in the south of Santa Catarina is related to the large agricultural production of rice and wood derivatives. This sector also generates a series of residues (straw, rice husks and wood sawdust) that are underutilized and could be used for energy production. As one of the reasons for the energy use of these materials, studies (Agostinetto et al., 2002; Lima et al., 1997; Mortele, 2011) are cited, pointing to the cultivation of rice irrigated by flooding as responsible for the emission of 10% to 16% of the methane produced throughout the country, the production of this gas being linked, in large part, to the decomposition of residues in the fields of crops.

Among renewable energy possibilities, biomass energy has the highest usage, accounting for 9% of the total primary energy supply in the world, of which 55.4% refers to traditional use (cooking and heating). It is estimated with reasonable assumptions that biomass has the potential to contribute much more to the global energy supply (Pradhan; Mahajani; Arora, 2018). Besides, biomass is referred as a carbon neutral fuel because there is no net addition of carbon dioxide to the atmosphere in its energy application, unlike fossil fuels.

The European Union defines the term biomass as the biodegradable fraction of products, rejects and residues from agriculture (plant and animal), forest residues and related industries, including the fishing industry and aquaculture, as well as the biodegradable fraction of industrial and municipal waste, also including biofluids such as vegetable oils (UE, 2009).

The high reactivity of biomass is a consequence of its physical and chemical characteristics. The volatile content is at least twice that of charcoal. The H/C and O/C molar ratios range from 1.3 to 1.5 and 0.5 to 0.6, respectively. These are higher values than those found for coals, which generally vary between 0.8 to 0.9 and 0.1 to 0.3 (Williams et al., 2012). A lower ratio implies more available energy, as C-C bonds have more energy than C-H or C-O bonds.

In Brazil there is a series of agricultural residues that are not managed and increase in quantity every year. The burning method is usually the most applied at the crop site because of the ease of application for elimination, but it becomes an air pollutant and causes the loss of mineral and water in the soil.

Two interesting biomass feedstocks in the southern of Santa Catarina are the leftovers from rice production and the different sources of wood by-products. The choice of using rice biomass (straw and husk) as a priority in this study is due to the vast area of approximately 150,000 hectares planted with rice in the state. The rice husk and straw are agricultural residues produced after the removal of rice from the field. Santa Catarina is the second national rice producer, with a production of 1.25 million tons (2020/2021 harvest), second only to the state of Rio Grande do Sul (Epagri, 2021). The largest rice production in Santa Catarina is in the southern region of the state, with a planted area of around 90,000 hectares.

The indicators for agricultural waste production can be divided into two categories, according to Kleveston (2011):

- ✓ Specific indicators: Present the residue production per unit of planted area of the main crop;
- ✓ Relative indicators: Correlate the waste production with the main crop production.

The relative indicators appear in the literature under a variety of names, such as SGR (Straw to Grain Ratio), harvest index, residue factor, residue-to-product ratio, among others.

As well as the relative indicators, the specific indicators also come under a variety of names. These indicators are highly dependent on factors such as climate, plant variety, cultural treatments such as fertilization, and soil in the region, among others. For some crops, variations of more than 50% are observed in the indices reported in the literature (Kleveston, 2011).

Nogueira and Lora (2002) presented an indicator of 4.30 t_{straw}/t_{rice} on dry basis; Kleveston (2011) pointed to a study carried out by the company *Plantar Serviços Agronômicos* in 2011, which shows a production in the southern region of Santa Catarina of around 4.8 t_{traw}/ha, which is equivalent to approximately 1 ton of straw per ton of grain harvested, the same value pointed out by Agrimec (2018). For rice husk, the values found are of the order of 0.20-0.27 t_{husk}/t_{rice} (Nogueira; Lora, 2002; Pers, 2018), being 20% the most adopted value.

The rice husk has no commercial value as a result of its hardness, fibrousness and abrasive nature and is normally used directly as fuel in boilers in the company where the rice is processed (Maia, 2013). However, a large amount is not commercially reused, and can be sold as natural fertilizer or discarded as waste.

Rice straw, on the other hand, is a fibrous material, obtained from the rejects of the rice grain harvesting machine and from the part of the plant that is not removed from the soil during harvesting (Miyake, 2011). Currently, it is used in soil incorporation, replacing part of the fertilizer. The flooded planting ground potentiates the formation of CH_4, which is more aggressive than CO_2 in the increase of the greenhouse effect (Miyake, 2011). Rice straw does not have high calorific value, the bulk density is low, and the amount of alkali and alkali compounds is significant (which can be a complicating factor in heat exchangers). All these characteristics make it difficult to handle, transport and store efficiently, thus limiting its commercial use (Kadam; Forrest; Jacobson, 2000).

Given the justifications presented above, this work collected and analyzed data on generation, quantity processed, and current USW treatment practices, as well as rice and forest biomass, in order to identify the potential for application in the development of USW-derived fuel and biomass that can be used in the energy and industrial markets.

METHODOLOGY

Collecting data from the region's waste

The field research made it possible to obtain the quantity of the main solid residues produced in the region, as well as to determine the concentration points of these materials in the south of the state of Santa Catarina.

The SNIS (Portuguese abbreviation for National Sanitation Information System - Sistema Nacional de Informações sobre Saneamento) was used as the main source of research. The SNIS is the largest and most important information system on the sanitation sector in Brazil, based on a database containing institutional, administrative, operational, managerial, economic-financial, accounting and quality information on the provision of water, sewage and solid urban waste management services (SNIS-RS, 2021). The SNIS information is collected annually and comes from service providers or municipal bodies in charge of service management, with the database being completely public and freely available at www.snis.gov.br.

The total volume of waste is composed of the portions of public waste (PPW) from sweeping or cleaning public areas and the household waste (HWA).

The evaluation of the collected data was organized by cities in increasing order of waste production in the southern region of Santa Catarina (Figure 1). It is noticed that more than 50% of the waste produced is concentrated in just four cities in the region (Criciúma, Tubarão, Imbituba, and Araranguá).

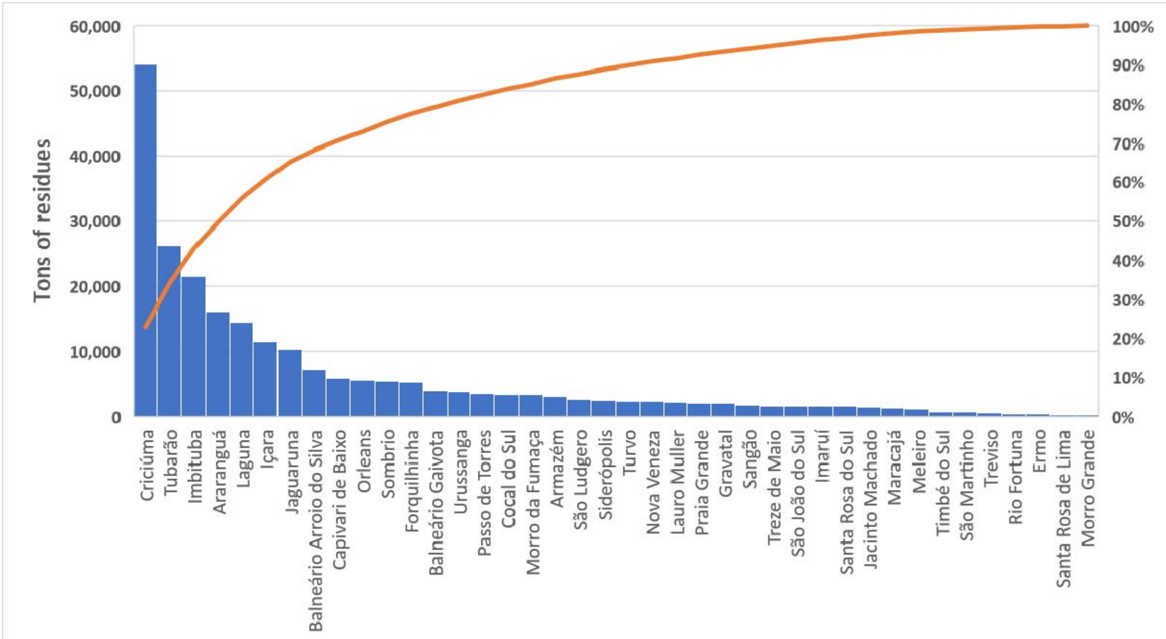

Figure 1. Residues produced by city in the southern region of Santa Catarina - 2020. Source: SNIS (2021).

Another analysis carried out was the distribution of municipalities by urban waste production per capita (Figure 2). It is believed that the variations obtained in relation to the total production of waste are the result of the local culture, population distribution in the municipality, tourist vocation, among other possibilities.

Additional data analysis was obtained from the information from the Waste and Tailings Handling Control System of the Santa Catarina Institute of the Environment – IMA. These data were made available aiming to create a mechanism to control the stages of the life cycle of a waste, through Law 15,251, of August 3, 2010, which instituted the Waste Transport Manifest. In 2014, the IMA launched, through Portaria FATMA 242/2014, the Control System for Handling Waste and Tailings, enabling the generation of these documents provided for by law (IMA, 2021).

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In 2019 the Waste Performance Bulletin of the State of Santa Catarina presented for the southern region of the state a movement of 1,360,879.67 tons of disposal and wood waste, 774,824.64 tons of chips, sawdust and wood pellets, not included in the initial item, as the two major blocks of waste movement in this region. Therefore, a total of 2,135,704.31 tons of wood biomass was moved in the south of Santa Catarina state, which also represents an important residue that can be used to obtain energy in the region (IMA, 2021).

The data from the State Plan for Solid Waste (Pers - Plano Estadual de Resíduos Sólidos) in the year 2018 indicate three points for the installation of landfills in the south of the state of Santa Catarina (Figure 3), being one in the city of Pescaria Brava, one in the region of Urussanga and another in the city of Içara (Pers, 2018).

The base year analyzed was 2020, based on a previous analysis of data, as being the year with the most recent and most complete data available on the query platform in relation to the municipalities under study. The total USW produced in the southern region of Santa Catarina in that year was accounted for as 236,272.2 tons.

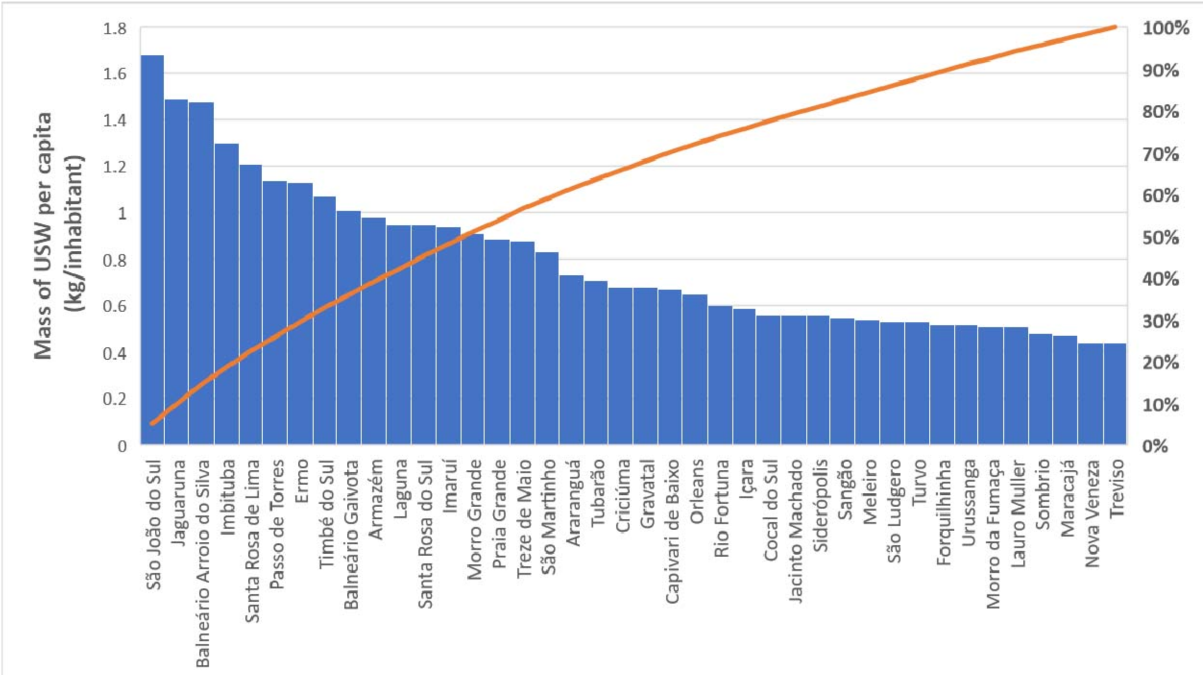

Figure 2. Residues produced per inhabitant in the southern region of Santa Catarina – 2020. Source: SNIS (2021).

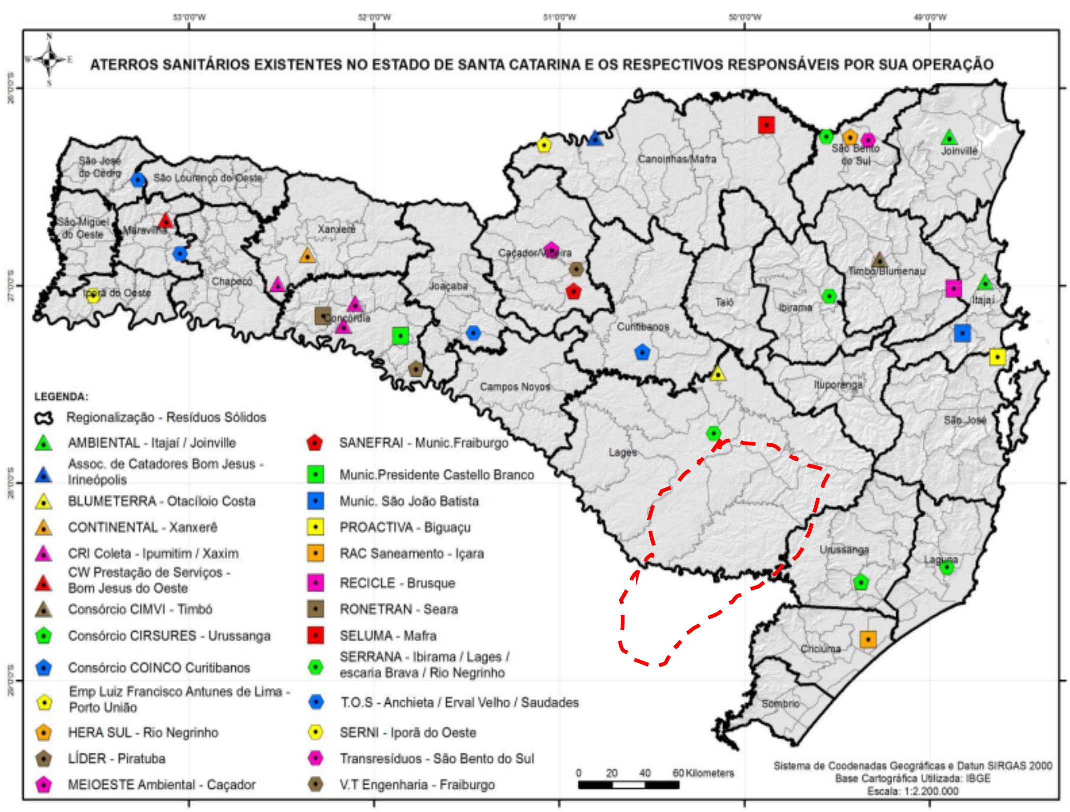

Figure 3. Landfills in Santa Catarina - southern region highlighted. Source: PERS (2018).

As can be seen, currently in Santa Catarina, due to the absence of sanitary landfills of their own or close to them, several municipalities dispose of their waste in units with significant distances, greatly increasing the overall management cost of the municipality with the transportation and final disposal of solid waste (Pers, 2018). A clear example can be seen in the Laguna Region (Table 1), where 12 cities centralize their waste in the Pescaria Brava landfill:

Table 1. Cities that send waste to the Pescaria Brava Landfill. Source: The author, 2021 (data from PERS (2018), distances calculated using Google Maps).

City	Distance from the landfill
Armazém	37 km
Capivari de Baixo	7.9 km
Gravatal	32 km
Imaruí	67 km
Imbituba	42 km
Jaguaruna	34 km
Laguna	23 km
Pescaria Brava	9.9 km
Sangão	40 km
São Martinho	52 km
Treze de Maio	40 km
Tubarão	15 km

An important information for determining the amount of energy in waste is its characterization (Pers, 2018; Soares, 2011). The PERS 2018 used to characterize the waste generated in the state, the gravimetry data obtained directly from the municipalities through a questionnaire or the data presented in the solid waste plans (municipal and intermunicipal). In the absence of data, for a given municipality, data from the weighted characterization of the state contained in the Master Plan for the Management and Treatment of Urban Solid Waste in the State of Santa Catarina were used. As an average for the state, the following composition was obtained: 43.86% for the organic fraction; 37.47% for recyclables; and 18.67% for tailings (Pers, 2018). The compositions are indicated in Figure 4.

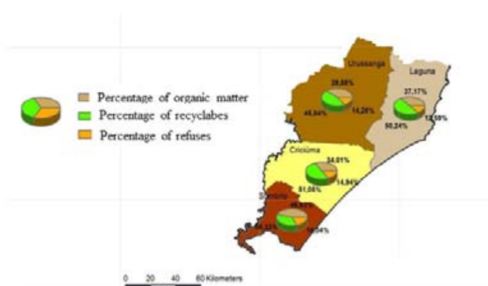

Figure 4. Gravimetric composition of USW in the south of Santa Catarina. Source: Adapted from PERS (2018).

Despite the available data sources, studies prove that each city has its own waste characteristics, and the amounts and diversities also vary throughout the year. In addition, society's behavior should be considered, as well as technological trends and cultural aspects (Gouveia, 2012; Souto; Povinelli, 2013).

As a way of exemplifying this characteristic of variation, the gravimetric composition is presented for some of the cities contemplated in the area under study, according to data from some works on the subject, as shown in Table 2.

Table 2. Gravimetric composition of USW in the south of Santa Catarina. Sources: 1-(GOMES, 2020); 2-(ROSSI, 2015); 3-(GUADAGNIN; SELAU; CADORIN, 2018).

City		Laguna/SC [1]	Araranguá/SC [2]	Criciúma/SC [3]
Residue type		**Mass percentage (%)**		
Organic		38.02	60	33.21
Paper/cardboard		11.29	9.5	13.67
Expanded polystyrene (Isopor)		0.72	4.5	13.18
Tetrapak		1.62		
Plastic film		12.55		
Rigid plastic		5.29		8.2
Glass		1.62	2.7	5.96
Metal	Aluminum	0.8	3.3	2.48
	Steel	2.05		
	Others	0.61		
Wood		0.24	15	23.3
Textiles and leather		5.39		
Sanitary		13.79	5	
hazardous waste (class I - ABNT)		5.05		
Others		0.96		

As the aim of this study is not the full use of urban solid waste for energy production, contemplating recycling as the most efficient method in the hierarchy of solid waste management (Vieira, 2019), it was verified, from a conventional recycling system, the average percentage of generation of non-recyclables, which would serve for this use.

The adopted model to verify the share of non-recyclables was the follow-up of a recycling cooperative implemented in the same region. A work cooperative of recyclable material collectors was used, which develops recycling activities at the Waste Sorting Center of the Municipality of Imbituba, located in the Vila Nova Alvorada neighborhood.

Table 3. Operational data of the recyclable material treatment cooperative in the city of Imbituba / SC. Source: The author (2021).

	Date	Jan/20	Feb/20	Mar/20	Apr/20	May/20	Jun/20	Mean	
1st semester	**Total collected (t)**	138.68	97.06	83.67	94.74	106.97	132.21	108.89	
	Waste generated (t)	26.70	18.18	9.85	18.39	15.90	20.77	18.30	
	Waste generated (%)	19.25	18.7	11.77	9.41	14.86	15.71	16.62	
	Date	**Jul/20**	**Aug/20**	**Sep/20**	**Oct/20**	**Nov/20**	**Dec/20**	**Mean**	**Annual mean**
2nd semester	**Total collected (t)**	118.60	128.93	114.71	127.69	137.37	159.19	131.08	**119.99**
	Waste generated (t)	33.20	28.67	30.92	44.64	39.00	29.02	34.24	**26.27**
	Waste generated (%)	27.99	22.24	26.95	34.96	28.39	18.23	26.4%	**21.54%**

The cooperative operates with the selective collection of recyclables, collecting a monthly average of almost 120 tons of material in the year 2020. By monitoring the institution's operation, it was possible to verify the average percentage of non-recyclables in a year of operation of the enterprise, which would be the quantities of material that could be used in fuel.

The average percentage obtained from a historical analysis (year 2020) referring to non-recyclable materials arriving at the enterprise was 21.54%. Monthly data can be seen in Table 3. For calculation purposes, the value of 20.0% was adopted as an annual average that could be applied to the region under study.The total waste produced by the city of Imbituba and other collection data are summarized in Table 4, obtained from the SNIS, for the base year of 2020.

Table 4. Waste generation data for the city of Imbituba / SC. Source: SNIS (2021).

Diagnosis - SNIS Features	**Imbituba**	
Population served	45,286	inhabitants
Waste generation in 2020	21,500,700	Kg
Per capita generation rate	1.3	Kg/hab
Recyclables recovered in 2020	1,350,000	Kg
Rate of recovered recyclable waste	6.279%	%
Landfill waste rate	93.721%	%
Estimated recyclable waste rate	50.00%	%

Available biomass options include residues from the wood industry (presented by the IMA survey) and from regional rice production. The priority choice for the use of rice biomass (straw or husk) can be understood by the large cultivated area in the southern region of Santa Catarina (Table 5), with approximately 100,000 hectares (Epagri, 2021). Besides that, IMA data have a higher degree of complexity to relate to the city of origin or destination. For this reason, they were not used in the study.

Table 5. The 11 mapped regions of rice cultivation and the total of Santa Catarina. Source: Adapted from EPAGRI (2021).

Region	**Area (ha)**	**%**
Araranguá	58,849	39.34%
Criciúma	21,912	14.65%
Tubarão	18,941	12.66%
Joinville	18,226	12.18%
Rio do Sul	10,695	7.15%
Itajaí	9,479	6.34%
Blumenau	7,123	4.76%
Tijucas	2,161	1.44%
Florianópolis	1,902	1.27%
Ituporanga	171	0.11%
Tabuleiro	132	0.09%
TOTAL	**149,591**	**100.00%**

The production of rice raised by EPAGRI (2021) was 1.25 million tons of grain in the 2020/21 harvest, of which one can expect a generation of about 1.5 million tons of biomass waste in the form of husk and straw for Santa Catarina. For the southern region, it can be estimated, by the cultivated area, a production of 999,750 tons.

The research pointed out that the generation of urban solid residues and biomass from rice culture in the southern region of Santa Catarina presents significant quantities for the production of thermal or electrical energy, lacking the development of logistics for collection, separation, and use.

CONCLUSIONS

The results of this work indicate a large generation of USW and biomass from rice culture in the southern region of Santa Catarina, with potential for its use to produce thermal or electrical energy. However, studies to develop logistics for collection, separation and use are necessary.

The Just Energy Transition (TEJ - Transição Energética Justa) is being implemented in Brazil. The national ordinary law nº 14.299, of January 5th 2022, created this Program; the decree nº 11.124, of July 7th 2022, provides for the TEJ Program Council and TEJ Plan for the Santa Catarina coal region; and the law nº 18.330, of January 5th 2022, instituted the TEJ State Policy and the Southern TEJ Hub of Santa Catarina State. These legal instruments focus on the valorization and efficient use of energy and mineral resources, laying an important solid foundation for the future energy transition.

In this context, the production of mixed fuel from USW and biomass can provide an alternative path of reuse for such materials, be an option for the immediate replacement of coal in thermoelectric generation, contributing to reducing the demand for landfill area, with the possibility of replacing a fraction of fossil fuel for a partially renewable alternative, starting a regional energy transition process, with environmental, economic, and social contributions.

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