

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.

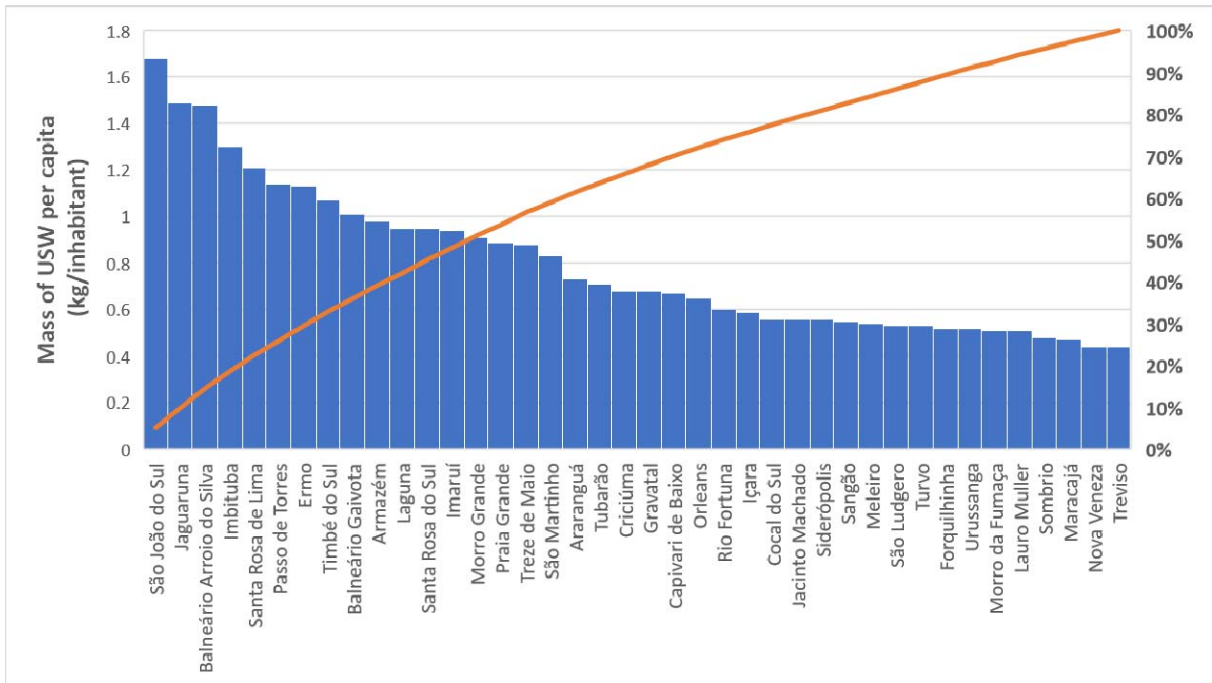


Figure 2. Residues produced per inhabitant in the southern region of Santa Catarina – 2020. Source: SNIS (2021).

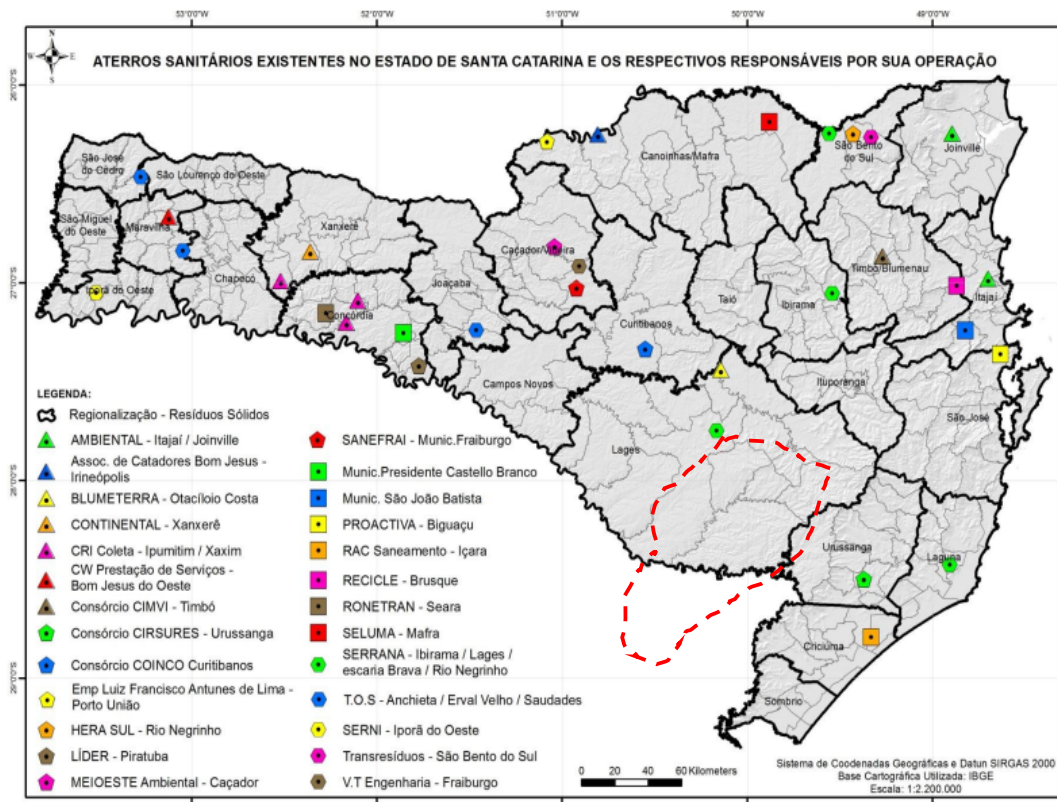


Figure 3. Landfills in Santa Catarina - southern region highlighted. Source: PERS (2018).

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.

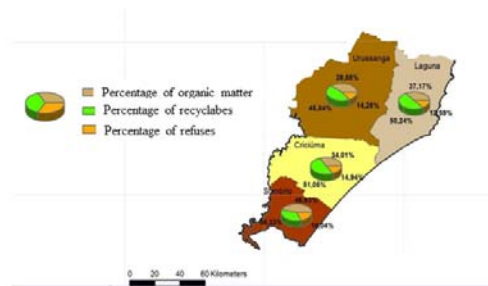


Figure 4. Gravimetric composition of USW in the south of Santa Catarina. Source: Adapted from PERS (2018).

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	
1 st 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
2 nd 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 n° 14.299, of January 5th 2022, created this Program; the decree n° 11.124, of July 7th 2022, provides for the TEJ Program Council and TEJ Plan for the Santa Catarina coal region; and the law n° 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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REFERENCES

- ABNT. Resíduos sólidos urbanos para fins energéticos - Requisitos. NBR 16849, 02/2020, 2020.
- Abrelpe. Panorama dos resíduos sólidos no Brasil 2018/2019. p. 1–64, 2019. Disponível em: <<https://abrelpe.org.br/panorama/>>. Acesso em: 9 fev. 2023.
- Agostinetto, D.; Fleck, N. G.; Rizzardi, M. A.; Balbinot Jr, A. A. Potencial de emissão de metano em lavouras de arroz irrigado. *Ciência Rural*, v. 32, n. 6, p. 1073–1081, 2002. Disponível em: <<https://doi.org/10.1590/S0103-84782002000600026>>.
- AGRIMEC. As melhores alternativas para o manejo da palha do arroz. 2018. Disponível em: <[https://agrimec.com.br/as-melhores-alternativas-para-o-manejo-da-palha-do-arroz/#:~:text=Uma das alternativas recomendadas para, facilitam o preparo do solo.>](https://agrimec.com.br/as-melhores-alternativas-para-o-manejo-da-palha-do-arroz/#:~:text=Uma%20das%20alternativas%20recomendadas%20para,%20facilitam%20o%20preparo%20do%20solo.>)>. Acesso em: 9 fev. 2023.
- Besen, G. R.; Fracalanza, A. P. Challenges for the sustainable management of municipal solid waste in Brazil. *Disp-The Planning Review*, v. 52, n. 2, p. 45–52, 2016. Disponível em: <<https://doi.org/10.1080/02513625.2016.1195583>>.
- Cetrulo, T. B.; Marques, R. C.; Cetrulo, N. M.; Pinto, F. S.; Moreira, R. M.; Mendizábal-Cortés, A. D.; Malheiros, T. F. Effectiveness of solid waste policies in developing countries: A case study in Brazil. *Journal of Cleaner Production*, v. 205, p. 179–187, 2018. Disponível em: <<https://doi.org/10.1016/j.jclepro.2018.09.094>>.
- Chen, H.; Zhang, M.; Xue, K.; Xu, G.; Yang, Y.; Wang, Z.; Liu, W.; Liu, T. An innovative waste-to-energy system integrated with a coal-fired power plant. *Energy*, v. 194, p. 116893, 2020. Disponível em: <<https://doi.org/10.1016/j.energy.2019.116893>>.
- Epagri. Safra catarinense de arroz se mantém estável em 2021, com produtividade superior no Sul do Estado. 2021. Disponível em: <<https://www.epagri.sc.gov.br/index.php/2021/07/23/safra-catarinense-de-arroz-se-mantem-estavel-em-2021-com-produtividade-superior-no-sul-do-estado/>>. Acesso em: 9 fev. 2023.
- Gomes, G. dos S. Avaliação do plano municipal de gestão integrada de resíduos sólidos e proposição de melhorias, Laguna, Santa Catarina, Brasil. 2020. Universidade Federal do Rio Grande do Sul, 2020. Disponível em: <<https://lume.ufrgs.br/handle/10183/206776>>. Acesso em: 9 fev. 2023.
- Gouveia, N. Resíduos sólidos urbanos: Impactos socioambientais e perspectiva de manejo sustentável com inclusão social. *Ciência & Saúde Coletiva*, v. 17, n. 6, p. 1503–1510, 2012. Disponível em: <<https://doi.org/10.1590/S1413-81232012000600014>>.
- Guadagnin, M. R.; Selau, C. C.; Cadorin, S. B. Gestão e gerenciamento de resíduos sólidos no município de Criciúma/SC. *Tecnologia e Ambiente*, v. 24, p. 159–180, 2018. Disponível em: <<https://periodicos.unesc.net/ojs/index.php/tecnoambiente/article/view/4372/4014>>.
- Guerrini, A.; Carvalho, P.; Romano, G.; Cunha Marques, R.; Leardini, C. Assessing efficiency drivers in municipal solid waste collection services through a non-parametric method. *Journal of Cleaner Production*, v. 147, p. 431–441, 2017. Disponível em: <<http://dx.doi.org/10.1016/j.jclepro.2017.01.079>>.
- Gug, J. I.; Cacciola, D.; Sobkowicz, M. J. Processing and properties of a solid energy fuel from municipal solid waste (MSW) and recycled plastics. *Waste Management*, v. 35, p. 283–292, 2015. Disponível em: <<http://dx.doi.org/10.1016/j.wasman.2014.09.031>>.

IMA. Boletim de desempenho-Resíduos Sólidos em Santa Catarina. p. 1–5, 2021. Disponível em:

<<https://www.ima.sc.gov.br/index.php/downloads/qualidade-ambiental/residuossolidos/boletim/2021-1/3470-dezembro-2>>. Acesso em: 10 dez. 2021.

Infiesta, L. R.; Ferreira, C. R. N.; Trovó, A. G.; Borges, V. L.; Carvalho, S. R. Design of an industrial solid waste processing line to produce refuse-derived fuel. *Journal of Environmental Management*, v. 236, p. 715–719, 2019. Disponível em: <<https://doi.org/10.1016/j.jenvman.2019.02.017>>.

Kadam, K. L.; Forrest, L. H.; Jacobson, W. A. Rice straw as a lignocellulosic resource: collection, processing, transportation, and environmental aspects. *Biomass and Bioenergy*, v. 18, n. 5, p. 369–389, 2000. Disponível em: <[https://doi.org/10.1016/S0961-9534\(00\)00005-2](https://doi.org/10.1016/S0961-9534(00)00005-2)>.

Kalinci, Y.; Dincer, I. Waste Energy Management. In: DINCER, I. (Ed.). *Comprehensive Energy Systems*. Chapter 5.3: Elsevier, 2018. v. 5, p. 91–133.

Kleverston, F. Metodologia de avaliação do potencial de resíduos agrícolas para conversão energética. 2011. Trabalho de Conclusão de Curso em Engenharia Mecânica - Universidade Federal de Santa Catarina, 2011.

Lima, M. A.; Neves, M. C.; Hermes, L. C.; Pessoa, M. C. P. Y. Estimativa de emissão de metano proveniente da cultura de arroz irrigado no estado de Santa Catarina. *Embrapa Meio Ambiente*, p. 562–564, 1997. Disponível em: <<https://ainfo.cnptia.embrapa.br/digital/bitstream/item/145711/1/1997PL005-MagdaLima-Estimativa-3349.pdf>>. Acesso em: 9 fev. 2023.

Maia, B. G. de O. Valorização de resíduos da rizicultura e bananicultura na produção de briquetes. 2013. Universidade da Região de Joinville (Univille), 2013. Disponível em: <https://www.researchgate.net/publication/286446506-Valorizacao_de_residuos_da_rizicultura_e_bananicultura_na_producao_de_briquetes>.

Miyake, R. G. Análise termodinâmica e de transferência de calor em um gerador de vapor a carvão pulverizado e palha de arroz. 2011. Mestrado em Engenharia Mecânica - Universidade Federal de Santa Catarina, 2011. Disponível em: <<http://repositorio.ufsc.br/xmlui/handle/123456789/95283>>.

Mortele, D. F. Efluxo de metano em solo sob manejos de irrigação e cultivares de arroz irrigado. 2011. Doutorado em Ciência do Solo - Universidade Federal de Santa Maria, 2011. Disponível em: <<https://repositorio.ufsm.br/handle/1/3329>>.

Nogueira, L. A. H.; Lora, E. E. S. *Wood Energy: Principles and Applications*. 2002. Disponível

em:

<https://www.researchgate.net/publication/228789648-Wood_energy_principles_and_applications>. Acesso em: 9 fev. 2023.

Pers, A. B. Plano estadual de resíduos sólidos de Santa Catarina: contrato administrativo nº 012/2016. 2018. Disponível em:

<<http://www.perssc.premiereng.com.br/documentos>>. Acesso em: 9 fev. 2023.

Pradhan, P.; Mahajani, S. M.; Arora, A. Production and utilization of fuel pellets from biomass: a review. *Fuel Processing Technology*, v. 181, p. 215–232, 2018. Disponível em: <<https://doi.org/10.1016/j.fuproc.2018.09.021>>.

Rossi, C. da R. Potencial de Recuperação Energética dos Resíduos Sólidos Urbanos na Região da AMESC. 2015. Engenharia de Energia-Universidade Federal de Santa Catarina, 2015. Disponível em: <<https://repositorio.ufsc.br/handle/123456789/128062>>

SNIS-RS. Sistema Nacional de Informações sobre Saneamento. 2021. Disponível em: <www.snis.gov.br>. Acesso em: 9 mar. 2023.

Soares, E. L. de S. F. Estudo da Caracterização Gravimétrica e Poder Calorífico dos Resíduos Sólidos Urbanos. 2011. Mestrado em Engenharia Civil - Universidade Federal do Rio de Janeiro, 2011. Disponível em: <http://objdig.ufrj.br/60/teses/coppe_m/ErikaLeiteDeSouzaFerreiraSoares.pdf>. Acesso em: 9 mar. 2023.

Souto, G. D. de B.; Povinnelli, J. Resíduos sólidos. In: Calijuri, M. C.; Cunha, D. G. F. (Ed.). *Engenharia ambiental: conceitos, tecnologia e gestão*. 2nd. ed. Rio de Janeiro: Elsevier, 2013. p. 445–464.

UE. Directive 2009/28/EC of the European parliament and of the council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. *Official Journal of the European Union*, p. 16–62, 2009. Disponível em: <<https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN>>. Acesso em: 9 fev. 2023.

Vieira, K. dos S. Análise da eficiência do gerenciamento dos resíduos sólidos urbanos no Brasil. 2019. Mestrado em Engenharia de Produção - Universidade Federal de Pernambuco, 2019. Disponível em: <<https://repositorio.ufpe.br/handle/123456789/34082>>.

Williams, A.; Jones, J. M.; MA, L.; Pourkashanian, M. Pollutants from the combustion of solid biomass fuels. *Progress in Energy and Combustion Science*, v. 38, n. 2, p. 113–137, 2012. Disponível em: <<https://doi.org/10.1016/j.pecs.2011.10.001>>.