Waste-to-Energy Technologies: a Systematic Literature Review

Nathalia Monteiro, Cristiano Dias Barros,
Giulia Evelen Nascimento de Barros,
Elizabeth Cristina Silva da Silva, Renata Oliveira and
Ailson Renan Santos Picanço

June 3, 2024

Waste-to-energy technologies: A systematic literature review

Nathalia Juca Monteiro[12][0000-0002-2619-2667], Cristiano Dias Barros[1], Giulia Evelen Nascimento de Barros[1], Elizabeth Cristina Silva da Silva[3], Renata Oliveira[14][0000-0002-1904-7533] and Ailson Renan Santos Picanço[1]

[1] Universidade do Estado do Pará, Belém, Brazil
[2] Pontificia Universidade Católica do Paraná, Curitiba, Brazil
[3] Universidade do Porto, Porto, Portugal
[4] INESC TEC, Porto, Portugal
nathalia.monteiro@uepa.br

Abstract. The global challenge of waste management has become prominent due to the increasing waste production, surpassing available disposal space. Simultaneously, the need to adopt renewable energy sources in response to the global energy crisis and climate change has intensified. In addressing this challenge, Waste-to-Energy (WTE) emerges as a solution, involving power generation and alternative fuel through waste treatment. This study adopts a portfolio approach to investigate WTE, identifying recommended technologies for effective implementation. Through a systematic literature review using the ProKnow-C methodology, we focused on papers published in English between 2018 and 2022, primarily from journals and conference proceedings on Science Direct and Scopus. From an initial pool of 2,214 papers (Scopus) and 1,364 papers (Science Direct), 53 were selected for thorough analysis, and 23 were included in the final portfolio due to their approach of the theme. Eight WTE technologies were identified: Pyrolysis, Incineration, Combustion, Gasification, Thermochemical Hydrolysis, Anaerobic Digestion, Fluidized Bed Combustion, and Composting. Incineration, known for its energy efficiency and significant waste volume reduction, was the most used technology. Pyrolysis, versatile and applicable to various waste types, ranked second, followed by gasification, which reduces greenhouse gas emissions. However, challenges, such as greenhouse gas emissions, highlight the environmental impact variability of WTE technologies. Despite drawbacks, WTE technologies persist as viable waste management and energy production alternatives, emphasizing the need for future studies to assess technology-specific criteria for precise application selection.

Keywords: Energy, Waste-to-energy, Technologies, Literature review.

1. Introduction

The 21st century society has been facing complex challenges, such as climate change, food and energy scarcity, and environmental pollution. Within the realm of environmental pollution, according to [1], the issue of solid waste generation stands out as a direct consequence of the logic of productivity and consumerism prevalent today. Production chains continually generate waste in this dynamic, depleting natural resources throughout this process.

Global waste production has reached a staggering 2.01 billion tons in 2016, as pointed out by [2]. Projections suggest that this figure will increase by almost 70% by 2050. To tackle this problem, it has been suggested that converting these waste residues into electricity for industrial use could be a viable solution [3]. Waste-to-energy (WTE) options can be defined as methods of optimizing existing waste disposal techniques while also providing an opportunity for energy recovery [4, 5].
The choice of technology for waste-to-energy conversion depends on waste characteristics, desired energy output, and local interests [5]. Active participation of the population in defining sustainable initiatives is crucial as it helps promote individual and collective responsibility [1], making civil society's involvement in this scenario necessary.
Despite the relevance of this subject, in 2020, 40.5% of the total generated waste was still improperly disposed of, with landfills receiving 1,664,765 tons [6]. To take a specific action, it is necessary to have a comprehensive understanding of WTE technologies available and how they can be utilized. To bridge this knowledge gap, this paper aims to report results of a systematic literature review and identify different WTE technologies presented in the literature guided by the following research question: Which WTE are presented in the literature as methods to convert solid residues in energy?

2. Method

To achieve the goal of the research paper, a thorough and structured review of relevant literature was conducted. To accomplish this goal, the methodology entitled Knowledge Development Process – Constructivist (ProKnow-C) was applied [7]. The methodology involved following a set of protocols to conduct searches and select articles for review, which were divided into different phases. In the first phase (Steps 1 to 4), a raw database of articles was constructed for consultation, while in the second phase (Steps 5 to 7), these articles were filtered and selected for in-depth study. The steps of ProKnow-C are presented in Table 1.

Table 1. ProKnow-C steps

Step	Description	Activities
Step 1	To define Keywords	Define search axes
		Set keywords of each axis
		Define keywords combinations
Step 2	To define database	Define the database according to the theme of the research
Step 3	To perform the search in Titles, Abstracts, and Keywords	Search databases using the keywords combinations
Step 4	Filtration of the gross article bank	Deleted repeated articles
Step 5		Read the titles

	Filtration of the gross articles not repeated	Exclude the articles misaligned with the theme
Step 6	Filtration of the bank of gross articles on scientific knowledge	Read abstracts
		Exclude the articles misaligned with the theme
		Article availability Search
		Exclude articles not available
Step 7	Filtration to the alignment of the comprehensive article	Read full article
		Exclude the articles misaligned with the theme

Source: Monteiro et al. [7].

Initially, a preliminary study of the subject was conducted to define the search axes and corresponding keywords for each identified axis. Two search axes and four keywords were utilized: Energy ("waste to energy", "WTE", "solid waste") and Manufacturing ("manufacturing"). Subsequently, three relevant databases were chosen for the field, Scopus, Web of Science, and Science Direct, to form the raw article database. The article filtering process was divided into two phases. In the first phase, duplicate articles were excluded, and documents were organized based on the emphases of their titles; subsequently, abstracts were examined to verify alignment with the research theme.
During the filtering phase, relevant research points were coded after article selection. A content analysis was conducted, and data were interpreted to identify the WTE.
In the course of our work, we found it necessary to make some adjustments. We decided to limit our search to a five-year period (2018 to 2022) to ensure the timeliness and relevance of the information we analyzed, based on the large number of articles we found in our preliminary search. This adjustment will allow our work to serve as a foundation for more in-depth studies in this area. Additionally, we chose to exclude the Web of Science database due to the limited number of relevant works it yielded.
In total, 3,578 articles were found, with 2,214 in the Scopus database and 1,364 in Science Direct. The articles were downloaded, and the Mendeley software was used to verify and eliminate duplicates. After this verification, 794 repeated works were excluded, resulting in 2,784 articles in the raw database.
After completing the second phase of the ProKnow-C method, 53 articles were left for thorough reading. 23 articles that covered the relevant areas of study were chosen as the basis for the research. The rest were excluded because they did not match the theme.

3. Results

The article set considers 23 pieces covering eight different waste-to-energy technologies, including Pyrolysis, Incineration, Combustion, Gasification, Thermochemical Hydrolysis, Anaerobic Digestion, Fluidized Bed Combustion, and Composting. A detailed description of these eight technologies is in Table 2.

Table 2. WTE technologies and their description.

WTE Technology	Description
Pyrolysis	The Chemical process involves the thermal decomposition of organic substances without oxygen [8].
Incineration	The process involves the controlled burning of solid waste in specialized facilities [9].
Combustion	An exothermic chemical process is one in which a substance reacts with an oxidant, usually oxygen, releasing energy in the form of heat and light [10].
Gasification	Chemical process that converts solid or liquid materials into combustible gas, known as syngas [11].
Thermochemical Hydrolysis	The process involves decomposing chemical substances through heat and water [12].
Anaerobic Digestion	Technology that involves the breakdown of organic waste in the absence of oxygen to produce biogas, which can be used to generate energy [13]
Fluidized Bed Combustion	The process of burning solid fuels occurs in an environment where the solids are suspended and fluidized by a continuous flow of air or another gas [13]
Composting	Natural biological process in which microorganisms decompose organic materials in a controlled environment to create compost, a nutrient-rich material that can be used as fertilizer to enrich the soil [14]

Considering the papers analyzed, the WTE technology that was most utilized and discussed is Incineration mentioned by 15 studies. This technology is highly popular due to its ability to reduce the amount of waste generated. Additionally, it is considered a safe method of disposing of hazardous wastes, among other benefits [15].

After incineration, the two most used technologies are Pyrolysis and Gasification, with 10 and 12 studies utilizing or analyzing the technologies, respectively. Pyrolysis is a widely used technique for producing energy using syngas, a mixture of hydrogen and carbon monoxide. This gas can be utilized as a source of energy in internal combustion engines or gas turbines [16]. Pyrolysis can also be applied to different waste materials and can be combined with other techniques, such as gasification and incineration, to increase efficiency and energy recovery [17].

Gasification, pyrolysis, and incineration are techniques that can be used for waste treatment and energy generation [18]. Gasification involves burning biomass with a limited air supply to generate gas [19].

While technologies provide numerous benefits, their utilization also brings along several problems, such as the emission of greenhouse gasses. The incineration process releases greenhouse gasses into the atmosphere, which raises concerns. Therefore, it is necessary to use emission control technologies to minimize the impacts caused by these emissions [20].

It is noteworthy that that there are limitations for the implementation of waste-to-energy approaches, such as high operational costs [21]. Therefore, it is crucial to carefully select the waste to be processed and implement effective recycling measures to ensure the sustainability and effectiveness of this approach [22].

4. Conclusion

The increasing amount of waste produced by society has become a pressing issue. Cities are struggling to handle the high volume and rapid pace of waste disposal. One potential solution to this problem is to harness the energy from this waste and utilize it for the benefit of industries, transportation, and society.

It is crucial to be aware of waste-to-energy technologies that are available to fulfill this role. This paper aims to identify these technologies by conducting a systematic literature review. This paper answers its research question by analyzing 23 papers, revealing the following technologies: Pyrolysis, Incineration, Combustion, Gasification, Thermochemical Hydrolysis, Anaerobic Digestion, Fluidized Bed Combustion, and Composting.

Some of these technologies can generate energy and reduce waste. However, they emit pollutant gasses and have high operational costs.

As this work was based on a systematic literature review, the research protocol has limitations in terms of the results obtained. Additionally, the WTE technologies were not observed in real scenarios. Therefore, it is recommended that future studies focus on evaluating the implementation of these technologies through case studies. This will enable researchers to identify the criteria for selecting these technologies.

References

1. Dos Santos, K.L., Besen, G.R., Jacobi, P.R., Sanches, G.L.: Resíduos sólidos urbanos na Macrometrópole Paulista: da sociedade de consumo aos desafios de gestão e governança. CONTRIBUCIONES A LAS CIENCIAS SOCIALES. 16, 1991–2007 (2023).

2. Lisbona, P., Pascual, S., Pérez, V.: Waste to energy: Trends and perspectives. Chemical Engineering Journal Advances. 14, 100494 (2023).

3. Kaya, K., Ak, E., Yaslan, Y., Oktug, S.F.: Waste-to-Energy Framework: An intelligent energy recycling management. Sustainable Computing: Informatics and Systems. 30, (2021).

4. Koldisevs, J., Fransson, T., Alberto, J., Gonzales, R.: Biogas production in rural areas of Mexico Biogas production in rural areas of Mexico Miroslav Petrov Commissioner EXERGIA, Mexico Contact person in industry. (2014)

5. Silva-Martínez, R.D., Sanches-Pereira, A., Ortiz, W., Gómez Galindo, M.F., Coelho, S.T.: The state-of-the-art of organic waste to energy in Latin America and the Caribbean: Challenges and opportunities. Renew Energy. 156, 509–525 (2020).

6. ABRELPE, Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais: panorama dos resíduos sólidos no Brasil 2020. (2020)

7. Monteiro, N.J., Gouvea Da Costa, S.E., Lima, E.P., Deschamps, F.: Energy and Industry 4.0: an Application of ProKnow-C Method. In: XXVI International Joint Conference on Industrial Engineering and Operations Management (2020)

8. Abushammala, M.F.M., Qazi, W.A.: Efficient approach for improving municipal solid waste management in Oman: Towards sustainable development. Int J Environ Waste Manag. 27, 345–362 (2021).

9. Aidonis, D., Achillas, C., Folinas, D., Keramydas, C., Tsolakis, N.: Decision support model for evaluating alternative waste electrical and electronic equipment management schemes-A case study. Sustainability (Switzerland). 11, (2019).
10. Tanveer, M., Khan, S.A.R., Umar, M., Yu, Z., Sajid, M.J., Haq, I.U.: Waste management and green technology: future trends in circular economy leading towards environmental sustainability. Environmental Science and Pollution Research. (2022).
11. Bagheri, M., Esfilar, R., Sina Golchi, M., Kennedy, C.A.: Towards a circular economy: A comprehensive study of higher heat values and emission potential of various municipal solid wastes. Waste Management. 101, 210–221 (2020).
12. Pluskal, J., Šomplák, R., Nevrlý, V., Smejkalová, V., Pavlas, M.: Strategic decisions leading to sustainable waste management: Separation, sorting and recycling possibilities. J Clean Prod. 278, 123359 (2021).
13. Manegdeg, R.F., Rollon, A., Ballesteros, F., Magdaluyo, E., De Sales-Papa, L., Clemente, E., Macapinlac, E., Ibañez, R., Cervera, R.B.: Waste-to-Energy Technology Suitability Assessment for the Treatment and Disposal of Medical, Industrial, and Electronic Residual Wastes in Metropolitan Manila, Philippines. In: ASME 2021 15th International Conference on Energy Sustainability. American Society of Mechanical Engineers (2021)
14. Khoshnevisan, B., Tabatabaei, M., Tsapekos, P., Rafiee, S., Aghbashlo, M., Lindeneg, S., Angelidaki, I.: Environmental life cycle assessment of different biorefinery platforms valorizing municipal solid waste to bioenergy, microbial protein, lactic and succinic acid. Renewable and Sustainable Energy Reviews. 117, 109493 (2020).
15. Mol, M.P.G.: A incineração de resíduos de serviços de saúde do município de belo horizonte/mg e a responsabilidade compartilhada (2011)
16. Silva, E.E., Rubenildo, L., Andrade, V., Daniel Martínez, J., Marco, Á., Haikal, A., Mateus, L., Rocha, H., Vilas Bôas De Sales Mónica, C.A., Gualdrón, A., Doris, M., Socorro, D., Coral, O.: Gaseificação e pirólise para a conversão Da biomassa em eletricidade e biocombustíveis, (2012).
17. Paradela, F.M.R.: Estudo da pirólise de misturas de resíduos de plásticos, pneus e biomassa, (2012)
18. Cui, W., Wei, Y., Ji, N.: Global trends of waste-to-energy (WtE) technologies in carbon neutral perspective: Bibliometric analysis, (2024)
19. Nandhini, R., Berslin, D., Sivaprakash, B., Rajamohan, N., Vo, D.V.N.: Thermochemical conversion of municipal solid waste into energy and hydrogen: a review, (2022)
20. Obaideen, K., Abdelkareem, M.A., Wilberforce, T., Elsaid, K., Sayed, E.T., Maghrabie, H.M., Olabi, A.G.: Biogas role in achievement of the sustainable development goals: Evaluation, Challenges, and Guidelines, (2022)
21. AlQattan, N., Acheampong, M., Jaward, F.M., Ertem, F.C., Vijayakumar, N., Bello, T.: Reviewing the potential of Waste-to-Energy (WTE) technologies for Sustainable Development Goal (SDG) numbers seven and eleven, (2018)
22. Tian, Y., Dai, S., Wang, J.: Environmental standards and beneficial uses of waste-to-energy (WTE) residues in civil engineering applications, (2023)