Unlocking sustainable futures: exploring feedstock composition for waste-to-energy solutions

A. Ramos

LAETA-INEGI, Associated Laboratory for Energy, Transports and Aerospace - Institute of Science and Innovation in Mechanical and Industrial Engineering, Rua Dr. Roberto Frias 400, 4200-465, Porto, Portugal
Keywords: waste management, biomass, waste valorization, waste-to-energy, sustainability.
Presenting author email: aramos@inegi.up.pt

The continuous expansion of a technology-driven society, the growing demands of industrial development, and a rising global population has resulted in an overwhelming accumulation of waste (Department 2022). This surge requires the development of efficient and environmentally sustainable methods for waste treatment and valorisation. Addressing this issue within the context of a sustainable development model presents not only a critical challenge but also a significant opportunity, being essential to prioritize waste prevention and minimize disposal needs (EUR-Lex 2008). When other alternatives prove unsuitable, waste-to-energy (WtE) technologies stand out as a practical solution, enabling the conversion of waste into energy, and other valuable resources, such as nutrients, chemicals and fuels (Tonini, Martinez-Sanchez et al. 2013, Ramos and Rouboa 2020).

The characteristics of waste differ significantly due to factors such as local climate, industrial activities or sources, waste management practices, and seasonal variations (Ramos and Rouboa 2020, Ramos 2023). Gaining insight into these variations is crucial for optimizing treatment processes and improving resource recovery. This study proposes a novel attempt to relate biomass composition to the optimal treatment technique and the related products achieved from the conversion. This was explored through an in-depth analysis of a variety of biomass and solid waste samples sourced from different world regions, aiming to uncover their properties and potential applications. A dedicated literature review was conducted to describe biomass source and composition, the management technique applied, and the valorisation route taken. The procedure to retrieve suitable literature for this study was as follows: keyword definition (waste characterization review; waste-to-energy; waste thermal valorisation), database selection (Search in Web of Science; Science Direct; Scopus; DOAJ), document type (reviews; research articles; conference abstracts; books; case reports), filtering for effective content, and finding duplicates. Figure 1 shows the main results in terms of publication rates according to year, treatment technique applied, and distribution of the achieved products.

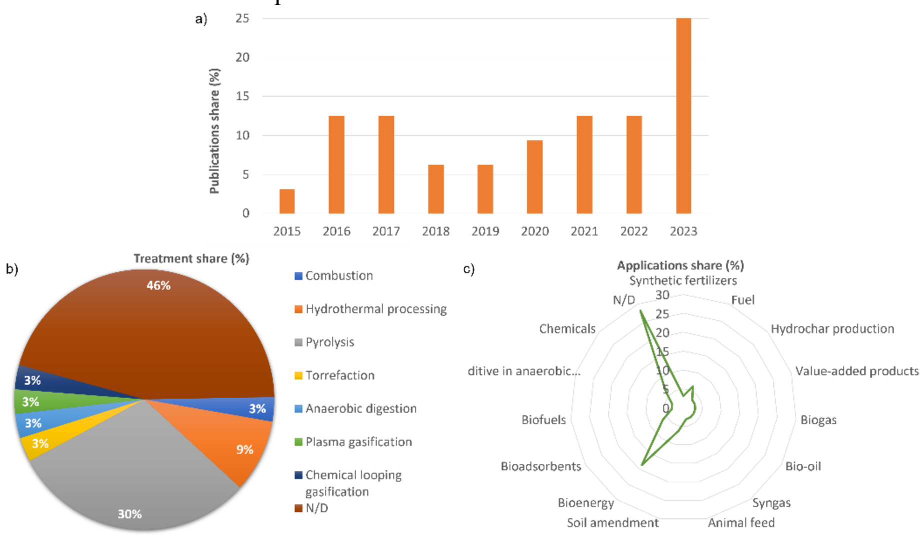

Figure 1. Literature distribution per: a) year; b) thermal treatment; c) application.

As seen in Figure 1a), literature on waste samples and their processing techniques has been steadily increasing since 2015, which might be linked to the release of several guidelines and frameworks related to circular economy principles, strategies, and the integration of waste management into these areas (Pan, Du et al. 2015, Webster 2015, Potting, Hekkert et al. 2017). Between 2018 and 2020, there was a noticeable decline in publications, maybe attributed to the introduction of initiatives such as the Ecodesign Directive (Commission 2017), the EU Green Deal (Commission 2019), and the New Circular Economy Action Plan (Commission 2020). Since 2022, however, there has been a resurgence in related publications. Figure 1b) depicts the biggest share of literature (46%) as not reporting the treatment technique applied to the feedstock, while around one-third of the studies focus on pyrolysis, nearly 10% utilize hydrothermal methods, and all the other techniques show 3% stake. These might be related to the need for pre-treatment stages before the conversion, raising the complexity and cost (Ramos, Monteiro et al. 2022, Monteiro, Ramos et al. 2024). Figure 1c) describes the final application/product, the highest portion being again attributed to publications that do not specify the final output (30%), whereas bioenergy represents roughly 19%, followed by fuels, soil amendments, bioadsorbents and chemicals (6.25% each). Other uses and products show minor contributions (around 3% share each). Some hampering indications might come from the ambiguous applications of terms (for instance “added value products” or “bioenergy”) (Adeniran, Adelopo et al. 2019), while some literature points the direction but do not clarify the final product (Liu, Basar et al. 2021, Yousef, Tamošiūnas et al. 2024).

This study highlights the growing interest in applying WtE techniques for recovering energy from various waste sources, with an increasing number of publications also addressing the concerns surrounding the significant rise in waste production. While the literature often fails to specify the exact conversion technique or final product, pyrolysis emerges as the most commonly applied method. Bioenergy is identified as the primary product, followed by fuels, soil amendment products, bioadsorbents, and chemicals. The trends observed here may not serve as a comprehensive rule or prediction for other scenarios or different feedstocks. However, for the specific types of waste and methods analyzed, this study can help identify gaps, challenges, and opportunities for greater implementation of technical solutions, as well as provide guidance for more efficient resource use and the optimization of WtE strategies.

Acknowledgements: This work is funded by national funds through the FCT – Fundação para a Ciência e a Tecnologia, I.P. and, when eligible, by COMPETE 2020 FEDER funds, under the Scientific Employment Stimulus - Individual Call (CEEC Individual) - 2021.03036.CEECIND/CP1680/CT0003. The author also acknowledges FCT support through project UIDB/50022/2020.

References:

Adeniran, A. E., A. O. Adelopo, A. T. Aina, A. T. Nubi and O. O. Apena (2019). "Energy Potential of Solid Waste Generated at a Tertiary Institution: Estimations and Challenges." Detritus **7**(7): 4-12.

Commission, E. (2017). The Ecodesign Directive (2009/125/EC) European Implementation Assessment. E. P. R. Service. Brussels, Ex-Post Evaluation Unit**:** 156.

Commission, E. (2019). "Delivering the European Green Deal." Retrieved 10-07-2024, 2024, from https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en.

Commission, E. (2020). A new Circular Economy Action Plan: For a cleaner and more competitive Europe. Communication, COM//98 final. E. Commission, European Commission. **Communication, COM//98 final**.

Department, S. R. (2022). Average annual per capita municipal waste generated by OECD countries as of 2022. S. R. Department, Statista.

EUR-Lex (2008). EU waste framework directive - Waste hierarchy. E. Union. EUR-Lex, European Union.

Liu, H., I. A. Basar, A. Nzihou and C. Eskicioglu (2021). "Hydrochar derived from municipal sludge through hydrothermal processing: A critical review on its formation, characterization, and valorization." Water Research **199**: 52.

Monteiro, E., A. Ramos and A. Rouboa (2024). "Fundamental designs of gasification plants for combined heat and power." Renewable and Sustainable Energy Reviews **196**: 114305.

Pan, S.-Y., M. A. Du, I.-T. Huang, I.-H. Liu, E. Chang and P.-C. Chiang (2015). "Strategies on implementation of waste-to-energy (WTE) supply chain for circular economy system: a review." Journal of Cleaner Production **108**: 409-421.

Potting, J., M. Hekkert, E. Worrell and A. Hanemaaijer (2017). Circular economy: measuring innovation in the product chain, PBL Publishers.

Ramos, A. (2023). "Considerations on waste characterization and the production of energy: how useful can waste be?" Detritus **24**: 3-12.

Ramos, A., E. Monteiro and A. Rouboa (2022). "Biomass pre-treatment techniques for the production of biofuels using thermal conversion methods – A review." Energy Conversion and Management **270**: 116271.

Ramos, A. and A. Rouboa (2020). "Renewable energy from solid waste: life cycle analysis and social welfare." Environmental Impact Assessment Review **85**: 106469.

Ramos, A. and A. Rouboa (2020). "Syngas production strategies from biomass gasification: Numerical studies for operational conditions and quality indexes." Renewable Energy **155**: 1211-1221.

Tonini, D., V. Martinez-Sanchez and T. F. Astrup (2013). "Material resources, energy, and nutrient recovery from waste: are waste refineries the solution for the future." Environ. Sci. Technol **47**(15): 8962-8969.

Webster, K. (2015). The circular economy: A wealth of flows. UK, Ellen MacArthur Foundation Publishing.

Yousef, S., A. Tamošiūnas, M. Aikas, R. Uscila, D. Gimžauskaitė and K. Zakarauskas (2024). "Plasma steam gasification of surgical mask waste for hydrogen-rich syngas production." International Journal of Hydrogen Energy **49**: 1375-1386.