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Editorial

Biomass Waste for Energy Production

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Abstract: Environmental problems associated with global energy supply systems and the increasing amount of global solid waste production are triggering a shift towards a greater reliance on biomass waste. Waste-to-energy systems have become important for industries and scientists because of the increasing interest in energy production from waste, due to improved efficiency and cost-effective solutions. The shift to biomass is also essential for industries to use their own waste to produce their own energy, which is in line with circular economy concepts. This Special Issue "Biomass Wastes for Energy Production" of *Energies* comprises ten (10) papers, including one review article, that represent the latest advances of waste-to-energy technologies and contribute to the rethinking of global energy supply systems. The Guest Editor also highlights other relevant topics that fall beyond the coverage of the published articles.

Keywords: biomass waste; waste-to-energy technologies; lifecycle analysis; circular economy; gasification; torrefaction; anaerobic digestion; equilibrium modeling

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1. Introduction

Climate change is forcing a rethinking of the world's energy supply system. Moreover, there is an increasing volume of biomass solid waste production worldwide. A shift toward a greater reliance on biomass waste is plausible due to major technological advances that hold the promise of biomass conversion into high-quality commodities such as electricity and gaseous or liquid fuels which are economically competitive with fossil fuels. Thus, waste-to-energy systems have become increasingly important for industries and scientists due to their interest in energy production from waste, with cost-effective solutions and improved efficiencies. The shift to biomass waste is also important for industries to become more efficient by using their own waste to produce their own energy, which is in line with the circular economy concept.

This Special Issue of *Energies* aims to publish the latest research on waste-to-energy technologies. The papers included will demonstrate the highly innovative and advanced scientific and engineering research in the field of waste-to-energy technologies and lifecycle assessment. This Editorial is organized as follows. Section 2 recapitulates the published articles in this Special Issue. Section 3 discusses several relevant topics beyond the coverage of the Special Issue. Lastly, the conclusion is drawn in Section 4.

2. Special Issue Performance

This section discusses each of the published articles in the main text but also recapitulates these in Table 1 as a complete overview of the Special Issue publications topics.

Table 1. Summary of the Special Issue articles.

Reference	Special Issue Topic	Specific Topic
Dyjakon and Noszczyk [1]	Waste-to-Energy	Torrefaction
Stępień et al. [2]	Waste-to-Energy	Torrefaction
Boer et al. [3]	Life-Cycle Analysis	Biomass Waste
Malmir et al. [4]	Life-Cycle Analysis	Waste Management
Dębowski et al. [5]	Waste-to-Energy	Anaerobic Digestion
Hoang et al. [6] *	Waste-to-Energy	Biomass Waste
Kozioł et al. [7]	Waste-to-Energy	Combustion
Calì et al. [8]	Waste-to-Energy	Gasification
Ferreira et al. [9]	Waste-to-Energy and Computational Models	Gasification
Copa et al. [10]	Waste-to-Energy and Cost Analysis	Gasification

* Review article.

Dyjakon and Noszczyk [1] proposed the torrefaction process of various forestry biomass residues as an initial treatment and as a means of preparing alternative fuels or substrates for other applications. Based on the results after the torrefaction process, the materials were characterized and showed good hydrophobic properties, calorific value and energy density. Considering the physical and chemical parameters, such as volatile matter, calorific value and fixed carbon content, forestry biomass resembles anthracite coal after torrefaction, but remains a biomass, a renewable source of energy.

Stępień et al. [2] studied the elephant dung torrefaction to determine the impact of operational parameters on the waste conversion rate and biochar properties. The produced biochars were characterized in terms of moisture content, organic matter, ash and calorific values. Furthermore, thermogravimetric and differential scanning calorimetry analyses were used for the process kinetics assessment. The results show that torrefaction is a feasible method for elephant dung valorization that can be used in households for heating and cooking.

Boer et al. [3] presented a lifecycle assessment of the integrated value chain from peach pruning residues for electricity generation and compared it to the common practices of the mulching process of the pruned biomass in orchards. The results show that biomass harvesting, chipping and its delivery to a power plant are feasible from an environmental perspective. The total global warming potential of this value chain was almost 12 times lower than the mulching and leaving of the pruned biomass in orchards.

Malmir et al. [4] carried out a lifecycle assessment for the current and proposed waste management system in Montréal city. A genetic algorithm was used to optimize the waste flows. Results showed that the current recovery ratio of organic waste of 23% could be increased to 100%. Moreover, recycling could be doubled and landfilling could be halved. The optimized waste flow for Montréal results in 58% for landfill, 32% for recycling, 2% for anaerobic digestion, 7% for compost and 1% for incineration.

Dębowski et al. [5] studied the performance of the anaerobic digestion of dairy wastewater in a multi-section horizontal flow reactor equipped with a microwave and ultrasonic generator. They found that organic loading rates had the greatest effect on the effects of anaerobic digestion of dairy wastewater in terms of organic compound removal and biogas and methane yields. They also found a considerable effect of ultrasonication on the effect of anaerobic digestion of dairy wastewater. An increase in ultrasonic intensity considerably reduced the efficiency of organic compound removal from wastewater, as well as biogas yield.

Hoang et al. [6] provided an overview of biomass streams that can be used for biogas production and their alternative uses. Their literature review was performed using the machine learning technique “co-occurrence analysis of terms”. They conclude that a large share of the biomass streams have many alternative uses, which limit their contribution to biogas production. Furthermore, there are some streams that have not been considered in the estimates for biogas production despite the fact that they have the appropriate characteristics.

Kozioł et al. [7] determined the energy and ecological characteristics of steam boilers when co-firing hard coal and biomass. Energy characteristics such as the dependence of the gross energy efficiency of boilers on such decision parameters as their efficiency and the share of biomass chemical energy in the fuel were determined. Ecological characteristics such as the dependence of gaseous emission streams and dust on the same decision parameters were determined. Boiler characteristics can be used when predicting the effect of the operating conditions on the existing, modernized and designed boilers.

Calì et al. [8] carried out an experiment to optimize and develop a fixed-bed updraft gasification process for power generation from biomass. Particular attention was paid to the optimization of an integrated double-stage wastewater management system designed to minimize both liquid residues and water make-up. They identified the optimal process parameters for the operation of the syngas cleaning system that results in a 60% reduction in wastewater disposal.

Ferreira et al. [9] performed an experimental and modeling analysis of brewers' spent grain gasification in a pilot-scale downdraft reactor. A ratio of 1.3 kg of brewers' spent grains per kWh of electricity generated was obtained, with an average electrical efficiency of 16.5 percent. A modified thermodynamic equilibrium model of the downdraft gasification was developed to assess the potential applications of various biomasses through produced gas quality indices. They concluded that when using air as the oxidizing agent, biomass gasification provides syngas with enough quality to be used for energy production in boilers or turbines.

Copa et al. [10] performed a techno-economic analysis of a small-scale (15 kWe) downdraft gasification system for electricity generation. An economic model was developed combining the net present value, internal rate of return and the payback period. A Monte Carlo sensitivity analysis was used to measure the performance of the economic model and determine the investment risk. The analysis showed an electricity production between 11.6 and 15 kW, with a general system efficiency of approximately 13.5%. The viability of the projects was predicted for an internal rate of return between 16.88 and 20.09 % and a payback period between 8.67 and 12.61 years. This study emphasizes the empowering effect of small-scale gasification systems employed in decentralized communities for electric power production.

3. Prospects for Future Developments

Besides the topics approached by this Special Issue, there are some waste-to-energy technologies and modeling techniques that were not covered. The Guest Editor would like to summarize the key topics—carbonization, pyrolysis, plasma gasification, supercritical water gasification and the numerical simulation methods and combustion characteristics of the syngas—in this section. Moreover, a few studies on the related fields are referenced as suggested readings in each field.

Waste-to-energy technologies have become important for industries and researchers due to climate change, the increasing amount of biomass waste production and the costs associated with its disposal. There are some relevant and emerging issues within the main topics of the Special Issue that were not explored by the ten articles published. These are the following:

- On the topic of biomass waste: Its availability, characterization and role in the circular economy. The availability of biomass waste should be achieved globally [11], especially due to its hazardous nature [12]. Moreover, there is a limited number of studies that discuss the characterization of biomass waste in terms of ultimate and proximate compositions, densification [13], heating power, etc. [14].
- On the topic of progress in waste-to-energy technologies. Carbonization, which is a renewed technique from which biocarbon is obtained from biomass waste [15,16], pyrolysis [17], which is suitable for bio-oil production, plasma gasification, which [18]

is suitable for hazardous waste elimination, and supercritical water gasification [19], which is suitable for high-moisture biomass waste, deserve to be developed. Although one article in this Special Issue studied the combustion characteristics of biomass in a boiler, our understanding of gasification gas combustion characteristics is limited; thus, it is necessary to improve our understanding in order to improve the market penetration of this technology. The references [20–22] are suggested as readings on this matter.

- On the computational models of biomass-based energy generation processes. There are several recent developments regarding this matter as expressed by Ramos et al. [23]. Specifically, a CFD plasma gasification model was developed by Ismail et al. [24] and CFD conventional gasification models are provided by [25,26].
- On the cost and performance analysis of waste-to-energy technologies. This topic was approached in one paper, but the same methodology should be applied to other biomass wastes, such as brewery biomass residues [27], sewage sludge and solid recovered fuels [28].

4. Conclusions

This Special Issue is composed of ten articles (one review paper) on various topics regarding biomass waste for energy production. Contributors have shared many valuable insights on the recent developments in this field. The Guest Editor has briefly summarized the details of each work and highlighted some emergent topics in the biomass and bioenergy field.

Thus, the development and advancement of waste-to-energy technologies is necessary in order to reshape global energy supply systems and make them consistent with the idea of a circular economy.

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References

1. Dyjakon, A.; Noszczyk, T. Alternative Fuels from Forestry Biomass Residue: Torrefaction Process of Horse Chestnuts, Oak Acorns, and Spruce Cones. *Energies* **2020**, *13*, 2468. [CrossRef]
2. Stępień, P.; Świechowski, K.; Hnat, M.; Kugler, S.; Stegenta-Dąbrowska, S.; Koziel, J.A.; Manczarski, P.; Białowiec, A. Waste to Carbon: Biocoal from Elephant Dung as New Cooking Fuel. *Energies* **2019**, *12*, 4344. [CrossRef]
3. Den Boer, J.; Dyjakon, A.; Den Boer, E.; García-Galindo, D.; Bosona, T.; Gebresenbet, G. Life-Cycle Assessment of the Use of Peach Pruning Residues for Electricity Generation. *Energies* **2020**, *13*, 2734. [CrossRef]
4. Malmir, T.; Ranjbar, S.; Eicker, U. Improving Municipal Solid Waste Management Strategies of Montréal (Canada) Using Life Cycle Assessment and Optimization of Technology Options. *Energies* **2020**, *13*, 5701. [CrossRef]
5. Dębowski, M.; Zieliński, M.; Kisielewska, M.; Kazimierowicz, J. Evaluation of Anaerobic Digestion of Dairy Wastewater in an Innovative Multi-Section Horizontal Flow Reactor. *Energies* **2020**, *13*, 2392. [CrossRef]
6. Hoang, D.L.; Davis, C.; Moll, H.C.; Nonhebel, S. Can Multiple Uses of Biomass Limit the Feedstock Availability for Future Biogas Production? An Overview of Biogas Feedstocks and Their Alternative Uses. *Energies* **2020**, *13*, 2747. [CrossRef]
7. Kozioł, J.; Czubala, J.; Kozioł, M.; Ziembicki, P. Generalized Energy and Ecological Characteristics of the Process of Co-Firing Coal with Biomass in a Steam Boiler. *Energies* **2020**, *13*, 2634. [CrossRef]
8. Calì, G.; Deiana, P.; Bassano, C.; Meloni, S.; Maggio, E.; Mascia, M.; Pettinau, A. Syngas Production, Clean-Up and Wastewater Management in a Demo-Scale Fixed-Bed Updraft Biomass Gasification Unit. *Energies* **2020**, *13*, 2594. [CrossRef]
9. Ferreira, S.; Monteiro, E.; Calado, L.; Silva, V.; Brito, P.; Vilarinho, C. Experimental and Modeling Analysis of Brewers' Spent Grains Gasification in a Downdraft Reactor. *Energies* **2019**, *12*, 4413. [CrossRef]

10. Copa, J.R.; Tuna, C.E.; Silveira, J.L.; Boloy, R.A.M.; Brito, P.; Silva, V.; Cardoso, J.; Eusébio, D. Techno-Economic Assessment of the Use of Syngas Generated from Biomass to Feed an Internal Combustion Engine. *Energies* **2020**, *13*, 3097. [CrossRef]
11. Teixeira, S.; Monteiro, E.; Silva, V.; Rouboa, A. Prospective application of municipal solid wastes for energy production in Portugal. *Energy Policy* **2014**, *71*, 159–168. [CrossRef]
12. Couto, N.; Silva, V.; Monteiro, E.; Rouboa, A. Hazardous Waste Management in Portugal: An Overview. *Energy Procedia* **2013**, *36*, 607–611. [CrossRef]
13. Monteiro, E.; Mantha, V.; Rouboa, A. The feasibility of biomass pellets production in Portugal. *Energy Source Part B.* **2013**, *8*, 28–34. [CrossRef]
14. Alves, O.; Passos, J.; Brito, P.; Gonçalves, M.; Monteiro, E. Characterization of municipal, construction and demolition wastes for energy production through gasification—A case study for a portuguese waste management company. In *Innovation, Engineering and Entrepreneurship*; Machado, J., Soares, F., Veiga, G., Eds.; Springer: Cham, Switzerland, 2019; Volume 505, pp. 619–625.
15. Alves, O.; Panizio, R.; Gonçalves, M.; Passos, J.; Calado, L.; Monteiro, E.; Brito, P. Carbonisation as a pre-treatment for rdf wastes prior to gasification. In *Wastes: Solutions, Treatments and Opportunities III*, 1st ed.; Vilarinho, C., Castro, F., Gonçalves, M., Fernando, A.L., Eds.; CRC Press: London, UK, 2019; Volume 3, pp. 543–548.
16. Alves, O.; Nobre, C.; Durão, L.; Monteiro, E.; Brito, P.; Gonçalves, M. Effects of dry and hydrothermal carbonisation on the properties of solid recovered fuels from construction and municipal solid wastes. *Energy Convers. Manag.* **2021**, *237*, 114101. [CrossRef]
17. Sharifzadeh, M.; Sadeqzadeh, M.; Guoa, M.; Borhani, T.N.; Konda, N.V.S.N.; Garcia, M.C.; Wang, L.; Hallette, J.; Shah, N. The multi-scale challenges of biomass fast pyrolysis and bio-oil upgrading: Review of the state of art and future research directions. *Prog. Energy Combust. Sci.* **2019**, *71*, 1–80. [CrossRef]
18. Oliveira, M.; Ramos, A.; Ismail, T.A.; Monteiro, E.; Rouboa, A. A Review on Plasma Gasification of Solid Residues: Recent Advances and Developments. *Energies* **2022**, *15*, 1475. [CrossRef]
19. Lee, C.S.; Conradie, A.V.; Lester, E. Review of supercritical water gasification with lignocellulosic real biomass as the feedstocks: Process parameters, biomass composition, catalyst development, reactor design and its challenges. *Chem. Eng. J.* **2021**, *415*, 128837. [CrossRef]
20. Monteiro, E.; Rouboa, A. Analysis of combustion flame of syngas-air mixtures. In Proceedings of the ASME Power Conference, Chicago, IL, USA, 13–15 July 2010.
21. Monteiro, E.; Sotton, J.; Bellenoue, M.; Moreira, N.A.; Malheiro, S. Experimental study of syngas combustion at engine-like conditions in a rapid compression machine. *Exp. Therm. Fluid Sci.* **2011**, *35*, 1473–1479. [CrossRef]
22. Monteiro, E.; Rouboa, A.; Bellenoue, M.; Boust, B.; Sotton, J. Multi-zone modeling and simulation of syngas combustion under laminar conditions. *Appl. Energy* **2014**, *114*, 724–734. [CrossRef]
23. Ramos, A.; Monteiro, E.; Rouboa, A. Numerical approaches and comprehensive models for gasification process: A review. *Renew. Sustain. Energy Rev.* **2019**, *110*, 188–206. [CrossRef]
24. Ismail, T.M.; Monteiro, E.; Ramos, A.; El-Salam, M.A.; Rouboa, A. An Eulerian model for forest residues gasification in a plasma gasifier. *Energy* **2019**, *182*, 1069–1083. [CrossRef]
25. Couto, N.; Silva, V.; Monteiro, E.; Brito, P.S.D.; Rouboa, A. Experimental and Numerical Analysis of Coffee Husks Biomass Gasification in a Fluidized Bed Reactor. *Energy Procedia* **2013**, *36*, 591–595. [CrossRef]
26. Ismail, T.M.; Ramos, A.; Monteiro, E.; El-Salam, M.A.; Rouboa, A. Parametric studies in the gasification agent and fluidization velocity during oxygen-enriched gasification of biomass in a pilot-scale fluidized bed: Experimental and numerical assessment. *Renew. Energy* **2020**, *147*, 2429–2439. [CrossRef]
27. Ferreira, S.; Monteiro, E.; Brito, P.; Castro, C.; Calado, L.; Vilarinho, C. Experimental Analysis of Brewers' Spent Grains Steam Gasification in an Allothermal Batch Reactor. *Energies* **2019**, *12*, 912. [CrossRef]
28. Alves, O.; Calado, L.; Panizio, R.; Gonçalves, M.; Monteiro, E.; Brito, P. Techno-economic study for a gasification plant processing residues of sewage sludge and solid recovered fuels. *Waste Manag.* **2021**, *131*, 148–162. [CrossRef]