# Refuse Derived Fuel

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One viable and robust form of waste-to-energy from municipal solid waste is refuse derived fuel (RDF). Generally, RDF refers to the segregated high calorific fractions of waste from MSW: household, commercial, or industrial process wastes. RDF from municipal solid waste particularly is sorted portions, which consist of combustible components such as waste plastics, paper, cardboard, textiles, and wood.

refuse derived fuel | energy recovery | solid waste management

## 1. Introduction

Among the significant challenges facing urbanization around the world is waste management. Globally, municipal solid waste generation (MSW) is rising. A total of 2.01 billion tons as of 2016 is expected to increase to about 3.40 billion tons by 2050 across various cities worldwide [1]. The effective management of municipal solid waste involves the application of approaches, technologies, and concepts that ensure the protection of public health and the environment. Recovering energy from waste is playing an increasing role in generating “low carbon” energy and meeting targets of energy from renewable sources. In 2018, countries within the European Union (EU) thermally treated 96 million tons of municipal solid waste with energy recovery according to the Confederation of European Waste-to-Energy Plant report [2]. Energy recovery from waste over the years has contributed to the global energy mix. This has contributed to meeting the rise in energy demand as the global population increases with industrialization and economic growth.

One viable and robust form of waste-to-energy from municipal solid waste is refuse derived fuel (RDF). Generally, RDF refers to the segregated high calorific fractions of waste from MSW: household, commercial, or industrial process wastes [3]. RDF from municipal solid waste particularly is sorted portions, which consist of combustible components such as waste plastics, paper, cardboard, textiles, and wood. It serves as an alternative way to reduce landfill waste and energy recovery from municipal solid waste. The utilization of refuse-derived fuel as a renewable energy resource also aligns with the Sustainable Development Goal 7: affordable and clean energy [4].

RDF is widely produced and utilized in most advanced economies such as Germany, Italy, Japan, China, Ireland, the USA and so on. [3]. Interest in energy recovery from MSW as refuse-derived fuel has also been extended to some developing countries such as India, Indonesia, Thailand [5], Mozambique, and Namibia [6]. For instance, about 7.5 MW of electricity is generated from RDF (heating value > 4000 kcal/kg) in India as of 2017 [7]. In the UK, the production of RDF in waste-to-energy facilities has contributed up to a 50% reduction in municipal solid waste

being landfilled in the last decade [8]. England also exported 2.6 million tons of RDF in 2019 [9]. Thus, RDF is recognized as a major alternative renewable energy resource.

However geographic distribution and impacts have not been the same. Although technologies exist, waste-to-energy research becomes specific since waste composition, energy needs, economies of scale, and infrastructure differ from one place to the other. Hence, research has not been widely distributed at the same pace. Thus, knowing the status of and various distribution of the scientific information concerning the RDF landscape is of special interest. Both quantitative and qualitative analysis represents an effective methodology to identify which field the research has been mainly directed in and analyze the important links between topics. Currently, bibliometric data analysis is widely used, and it allows objective quantitative analysis. Although this methodology is not new, as its use started back in the 1970s from the Scopus database [10], its proliferation is fairly recent, as seen in many fields on average in the last decade [11]. In bibliometric analysis, the scientific data collected for analysis are codified and ordered and come from global scientific publication databases, for example, Scopus, Web of Science, PubMed, Dimensions and so on. Bibliometrics is an important tool for determining research trends. Studies with bibliometrics have been conducted in various fields; for instance, in engineering on soil erosion modeling [12] and industrial waste water treatment [13], on circular economy in the building and construction sector [14], and an analysis of the potential uses of brewer's spent grains in a biorefinery for the circular economy transition [15]. In energy and environment, bibliometric analysis has presented research trends in biomass and biofuels [16][17], energy security [18], nuclear energy research [19], and energy research trends from specific geographic locations [20][21], and in social science [11].

## 2. Country/Territory Performance

Contributions from countries/territories to the body of knowledge in the area of RDF as found out in **Figure 1**. High publication counts were recorded from the United States, Europe (Italy, Germany, UK, and Poland), and Asian countries (India, China, Japan, and Thailand). A total of 1174 publications with author information were obtained from 74 countries that have contributed to this area. There was a limited contribution to the literature from Oceania and African countries; none were among the top 10. Considering developing countries in general, an appreciable number of works were reported from India (51), Thailand (48), Indonesia (41), South Africa (8), Jordan (7), and Morocco (2). This shows that research interest is growing, which is encouraging. However, studies from some African countries (Algeria, South Africa, Morocco, and Nigeria, were recorded in recent times (2015 to 2021), representing a contribution of less than 1%. This is in line with the GIZ report as waste-to-energy systems are limited in most developing countries with very few successful cases [22]. Thus, the need for more studies on RDF from non-western countries' perspectives is more pronounced.

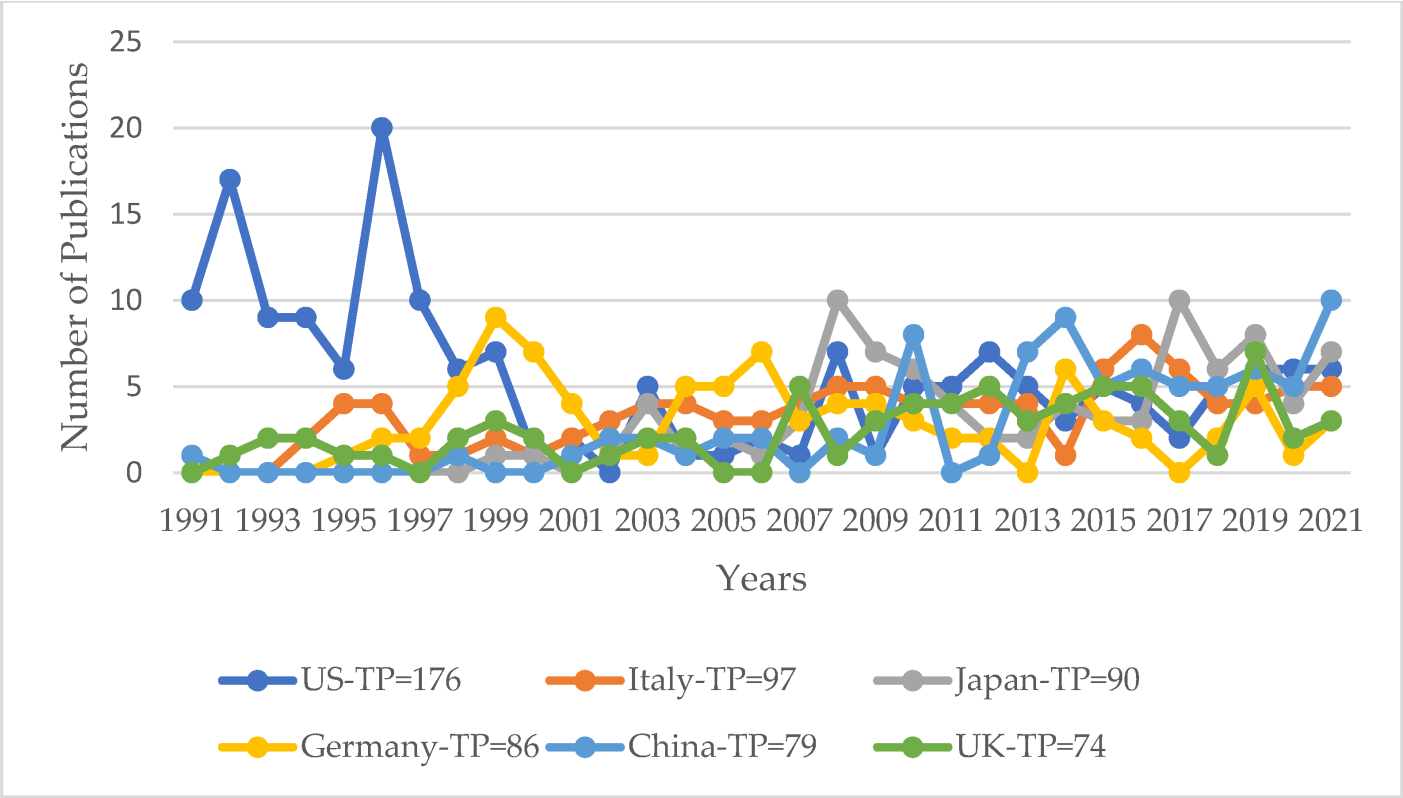


**Figure 1.** Number of publication by country.

The time-trend analysis of the 6 most productive territories is presented in **Figure 1**. Observably, the US had a leading position during the period of analysis, although publications declined along subsequent years. Similarly, the research growth trend rate was high in other developed countries such as Italy, Germany, the UK, and China. Arguably, one possibility of contribution is from the waste-to-energy policies and strategies instituted by advanced economies such as in the EU. The introduction of regulations in the European Union directives such as zero landfill within the EU strengthened the research in the area of RDF as an alternative fuel and its valorization. As such, energy recovery and GHG emissions reduction from waste draw more attention in these countries. In 2005, Germany adopted a ban on the landfilling of recyclable and organic waste, leading to overproduction of RDF as well as the cement sustainability initiative [23]. On the contrary, research interest observed from China, India, Indonesia, and other Asian countries could be driven by the high population density and the need to find solutions to waste management and the experiences of difficulties to locate suitable sites for landfills [24]. This has motivated more research on MSW and residual waste as alternative fuels.

## 3. Country Collaboration

A total of 64 countries had engaged in collaborative works from the country co-authorship mapping, as shown in **Figure 2**, forming seven clusters with 179 links. In Cluster I, the UK was central among 14 nodes and 17 links between countries or territories around the world in RDF-related research. Sweden, Italy, and China had the closest collaboration, while others included Canada, Spain, Botswana, and Morocco. Clusters II and IV were

largely made up of Asian and European countries. China and Italy were the central nodes in Cluster II. A total of 11 links of collaboration were observed between Italy and countries such as Romania, Spain, Germany, Austria, Portugal, Belgium, Netherlands, Taiwan, Sweden, and the UK. Among these, Romania and Italy had the largest collaboration with a link strength of seven. China had a total of 19 links with other countries such as Germany, Japan, and Finland. The central node of Cluster IV (14 links) was Japan, a strong collaboration with Thailand and Indonesia. The US was central in Cluster III, with a total of 10 nodes and 23 links of collaboration. Strong links also existed between Poland (nine), Japan (five), and Greece (five). Others were between US and Germany, Thailand, and China. Germany had collaborations existing between Austria, China, Brazil, the Czech Republic, Jordan, and Algeria. India was central in Cluster VI and had 10 links of collaboration, while Sweden in Cluster V exhibited 14 links of collaboration.

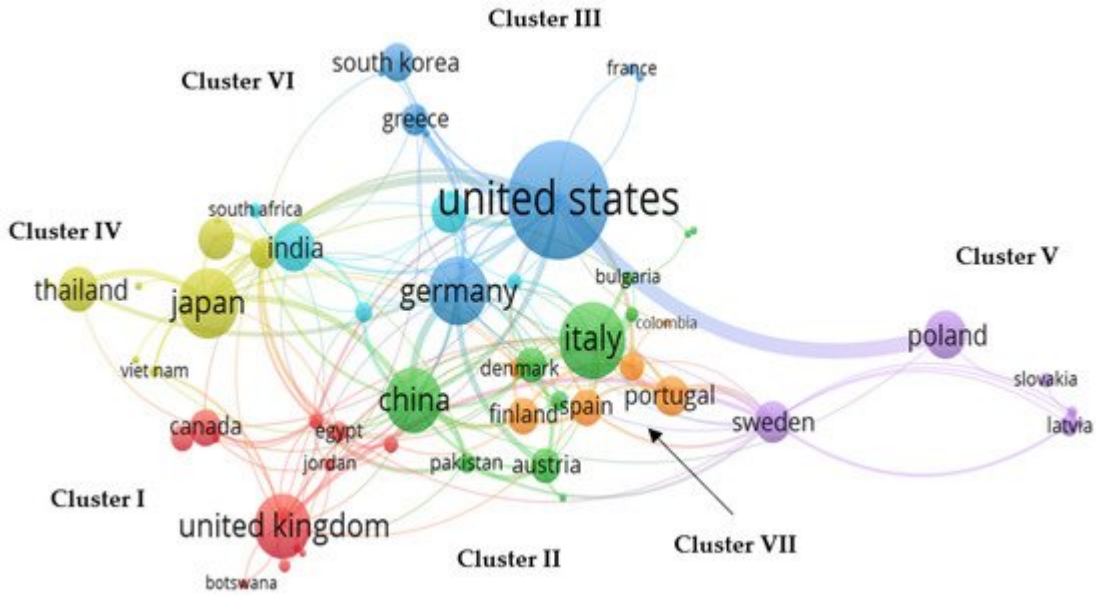


**Figure 2.** Collaborations among countries based on publications (co-authorship analysis; a minimum of 1 was applied to the number of publications by a country. A total of 64 out of 74 met the threshold in VOSviewer displayed).

Generally, the majority of collaborations were among European countries as well as between Europe and the US. This was observed in other studies such as in food waste research [25], biomass analysis [17], and education [11]. Some collaborations also existed between Asian and European territories. This justifies a lot of research and practice within waste-to-energy originating from these areas [13]. EU specifically consumed RDF of about 5 million tons in a cement kiln according to the European cement Association in 2015 [26]. India generates about 7.5 MW of electricity from RDF [7], while about 13 RDF-based facilities exist in the US [5]. Thus, the correlation between the research output and RDF production (implementation) is strong, showing a higher performance of academic influence and active international cooperation. The top 10 countries are coherent in maintaining considerably high levels in both parameters since there is the dedication to research resources and, at the same time, develop and install systems in that regard. This explains their tags as leads in the production and use of RDF [6] and thus the production of technology and scientific developments in the area.

Nevertheless, the possibilities of RDF production and utilization in currently non-utilising countries worldwide exist. As for sub-Saharan African region, there are large potentials for RDF as a result of growing MSW generation and industrialization, whereas the prevalent form of MSW management is landfilling. Thus, RDF could contribute to meeting industrial energy needs and the energy poverty gap with decentralized systems [27]. For instance, in Nigeria, Kenya, Ghana, Togo, Uganda, and Algeria, where cement production is growing [28] with less investment in waste-to-energy [29], there exist large potentials for RDF utilization. Among the challenges facing the local cement production industry include high energy costs [28][30]. However, there are success stories from Namibia in terms of RDF utilization in cement production to learn from [31]. An investment in research of RDF is significant to bridge the gap, while it will also complement efforts at implementing waste management strategies with a focus on waste-to-energy.

## 4. Conclusions

Bibliometric and network analysis of literature in refuse-derived fuel research from the Scopus database is presented. The data and analysis showed research within the refuse-derived fuel sphere stems back from the 1970s. Much of the development was found to be contributed from the US, China, Germany, and India. There are comparatively fewer contributions from the African region. Several locations within the sub-Saharan region are underdeveloped in terms of this theme, as issues on waste management and waste-to-energy become contextually driven. It was showed that the cooperation of countries was limited to specific territories: the US, Europe, and some Asian countries. This shows the need for improved efforts towards research collaboration within the field. This would improve the limited research contribution from especially developing countries and related issues of implementation. International collaborations also unveil opportunities for capacity building and technology transfer. The key journal sources of publications on refuse derived fuel included Waste Management, Fuel, Waste Management and Research, and the Journal of Cleaner Productions. Meanwhile, research was within the subject areas of environmental science, energy, and engineering. The thematic scope of the analyzed publications was diverse: conversion process, utilization, and management. Popularly, research in RDF application was in the cement process and electricity generation. Although a lot of research has been undertaken decades ago, there is still the need for advancement in processes, applications, and prospects. Few studies have been reported on thermochemical upgrading of RDF, material recovery (foe example, hydrogen, as adsorbent, use of ash) other than energy from RDF and LCA(life cycle assessment) as the main research focus. Furthermore, circular economy and sustainability are in recent times highly rated and have become the direction for the most research. In times of diverse growth in technologies and advanced knowledge, AI and IoT may be possible for applicable future research needs or reshaping the existing research.

## References

1. The World Bank Solid Waste Management. Available online: https://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management (accessed

on 29 September 2021).

2. CEWEP. Waste-to-Energy: Energising Your Waste. Available online: https://www.cewep.eu/wp-content/uploads/2018/07/Interactive-presentation-2018-New-slides.pdf (accessed on 29 September 2021).
3. Gendebien, A.; Leavens, A.; Blackmore, K.; Godley, A.; Lewin, K.; Whiting, K.J.; Davis, R.; Giegrich, J.; Fehrenback, H.; Gromke, U.; et al. Refuse Derived Fuel, Current Practice and Perspectives. Available online: https://www.undrr.org/organization/european-commission-directorate-general-environment (accessed on 1 April 2020).
4. Ribeiro, A.; Soares, M.; Castro, C.; Mota, A. Waste-to-Energy Technologies Applied for Refuse Derived Fuel (RDF) Valorisation. HELIX 2019, 641–647.
5. Yang, Y.; Liew, R.K.; Tamothran, A.M.; Foong, S.Y.; Yek, P.N.Y.; Chia, P.W.; Tran, T.V.; Peng, W.; Lam, S.S. Gasification of Refuse-Derived Fuel from Municipal Solid Waste for Energy Production a Review.Pdf. Environ. Chem. Lett. 2021, 19, 2127–2140.
6. Lee, R.D. Evaluating Uganda's Waste Management System for the Production of Refuse-Derived Fuel (RDF) and Its Potential Implementation in the Country's Growing Cement Industry. 2019. Available online: https://catalogplus.tuwien.at (accessed on 15 April 2021).
7. Shukla, P. Utilization of Refuse–Derived Fuel (RDF) as an Alternative Energy Resource in India. Int. J. Innov. Res. Sci. Eng. Technol. 2017, 6, 7537–7542.
8. Brew, M. What's on the Horizon for Refuse-Derived Fuel as Brexit Looms and Production Evolves. Available online: https://www.recyclingwasteworld.co.uk/in-depth-article/as-brexit-looms-and-production-evolves-whats-on-the-horizon-for-refuse-derived-fuel/172555/ (accessed on 13 November 2021).
9. Langley, J. RDF Exports. Available online: https://www.letsrecycle.com/news/rdf-exports-fall-by-more-than-a-third-in-2020/ (accessed on 13 November 2021).
10. Scopus Bibliometric Analysis. Available online: https://www.scopus.com/results/results.uri?cc=10&sort=plf-t&src=s&nlo=&nlr=&nls=&sid=da8e155b980334a7caff0569f81d04b4&sot=b&sdt=b&sl=38&s=TITLE-ABS-KEY%28%22Bibliometric+analysis%22%29&ss=plf-t&ps=r-f&editSaveSearch=&origin=resultslist&zone=resultslist (accessed on 19 November 2021).
11. Moosa, V.; Shareefa, M. Science Mapping the Most-Cited Publications on Workplace Learning. J. Work. Learn. 2020, 32, 259–272.
12. Bezak, N.; Borrelli, P.; Alewell, C.; Alvarez, P.; Alexandre, J.; Anache, A.; Baartman, J.; Ballabio, C.; Chalise, D.; Chen, S.; et al. Soil Erosion Modelling: A Bibliometric Analysis z Miko. Environ. Res. 2021, 197, 111087.

13. Mao, G.; Hu, H.; Liu, X.; Crittenden, J.; Huang, N. A Bibliometric Analysis of Industrial Wastewater Treatments from 1998 to 2019. Environ. Pollut. 2020, 275, 115785.
14. Cabeza, L.F.; Jim, L.; Norouzi, M.; Ch, M.; Boer, D. Circular Economy in the Building and Construction Sector: A Scientific Evolution Analysis. J. Build. Eng. 2021, 44, 102704.
15. Sganzerla, W.G.; Ampese, L.C.; Mussatto, S.I.; Lyngby, K. A Bibliometric Analysis on Potential Uses of Brewer's Spent Grains in a Biorefinery for the Circular Economy Transition of the Beer Industry. Biofuels Bioprod. Biorefining 2021, 15, 1965–1988.
16. Mao, G.; Zou, H.; Chen, G.; Du, H.; Zuo, J. Past, Current and Future of Biomass Energy Research: A Bibliometric Analysis. Renew. Sustain. Energy Rev. 2015, 52, 1823–1833.
17. Ferrari, G.; Pezzuolo, A.; Nizami, A.-S.; Marinello, F. Bibliometric Analysis of Trends in Biomass for Bioenergy Research. Energies 2020, 13, 3714.
18. Zhou, W.; Kou, A.; Chen, J.; Ding, B. A Retrospective Analysis with Bibliometric of Energy Security. Energy Rep. 2018, 4, 724–732.
19. Obregón, L.; Orozco, C.; Camargo, J.; Duarte, J.; Valencia, G. Research Trend on Nuclear Energy from 2008 to 2018: A Bibliometric Analysis. Int. J. Energy Econ. Policy 2019, 9, 542–551.
20. Adedayo, H.B.; Adio, S.A.; Oboirien, B.O. Energy Research in Nigeria: A Bibliometric Analysis Energy Research in Nigeria: A Bibliometric Analysis. Energy Strateg. Rev. 2021, 34, 100629.
21. Alemán-Nava, G.S.; Casiano-Flores, V.H.; Cárdenas-Chávez, D.L.; Díaz-Chavez, R.; Scarlat, N.; Mahlknecht, J.; Dallemand, J.-F.; Parra, R. Renewable Energy Research Progress in Mexico: A Review. Renew. Sustain. Energy Rev. 2014, 32, 140–153.
22. Mutz, D.; Hengevoss, D.; Hugi, C.; Gross, T. Waste-to-Energy Options in Municipal Solid Waste Management-A Guide for Decision Makers in Developing and Emerging Countries. Dtsch. Ges. Für Int. Zs. GmbH 2017, 1–58.
23. IFC-World Bank Group. Increasing The Use of Alternative Fuels at Cement Plants: International Best Practice; International Finance Corporation: Washington, WA, USA, 2017.
24. Wang, Y.; Lai, N.; Zuo, J.; Chen, G.; Du, H. Characteristics and Trends of Research on Waste-to-Energy Incineration: A Bibliometric Analysis, 1999–2015. Renew. Sustain. Energy Rev. 2016, 66, 95–104.
25. Zhang, M.; Gao, M.; Yue, S.; Zheng, T.; Gao, Z.; Ma, X.; Wang, Q. Global Trends and Future Prospects of Food Waste Research: A Bibliometric Analysis. Environ. Sci. Pollut. Res. 2018, 25, 24600–24610.
26. The European Cement Association. Data and Assessments on Markets for SRF Production of SRF Based on Waste Volumes Current Use of SRF/RDF Potential Markets for SRF; CEMBUREAU: Brussels, Belgium, 2015.

27. Lucas, P.L. Towards Universal Electricity Access in Sub-Saharan Africa A Quantitative Analysis of Technology. 2017. Available online: https://www.pbl.nl/sites/default/files/downloads/pbl-2017-towards-universal-electricity-access-in-sub-saharan-africa-1952_3.pdf (accessed on 5 February 2021).
28. Barnes, R. Cement Production in Africa and Pricing and Trends. Available online: https://constructionreviewonline.com/concrete/cement-production-in-africa-and-pricing-and-trends/ (accessed on 29 December 2021).
29. Alqattan, N.; Acheampong, M.; Jaward, F.M.; Cansu, F. Reviewing the Potential of Waste-to-Energy (WTE) Technologies for Sustainable Development Goal (SDG) Numbers Seven and Eleven. Reinf. Plast. 2018, 27, 97–110.
30. Dawson-Ahmoah, G. Local Cement Industry Is Suffering. Available online: https://www.modernghana.com/news/1070633/article-local-cement-industry-is-suffering.html (accessed on 20 April 2021).
31. Ohorongo Cement Ohorongo Cemen Invest in Refuse Derived Fuel. Available online: https://www.ohorongo-cement.com/search/?search_field=refuse+derived+fuel&search=Submit (accessed on 21 April 2021).