Review

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Harnessing Agricultural Waste for Sustainable Biodiesel Production: A Comprehensive Review

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Review

Harnessing Agricultural Waste for Sustainable Biodiesel Production: A Comprehensive Review

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Abstract*:* Agricultural waste has garnered increasing attention as a promising and sustainable feedstock for biodiesel production, offering a pathway to reduce reliance on fossil fuels and address environmental challenges. This comprehensive review delves into the potential of utilizing agricultural residues such as crop husks, fruit peels, and other organic by-products for biodiesel synthesis, emphasizing the transformative role of **biochar** in this process. The review explores advancements in conversion technologies, including pyrolysis and transesterification, which enable the effective transformation of agricultural wastes into biodiesel. Biochar's application as a heterogeneous catalyst significantly enhances the efficiency and sustainability of these processes, offering a cost-effective and environmentally friendly alternative to traditional catalysts. The study also examines various modifications of biochar, such as chemical and physical treatments, which further optimize its catalytic properties and expand its applications in biodiesel synthesis. In addition to technological advancements, this review highlights the socio-economic benefits of leveraging agricultural waste and biochar, such as waste valorization, rural economic development, and contributions to the circular economy. It also addresses challenges like feedstock variability, collection logistics, and the need for robust policy frameworks to support agricultural waste-based biodiesel production. By integrating biochar into biodiesel production systems, this review provides a comprehensive roadmap for harnessing agricultural waste to achieve renewable energy goals.

Keywords: biochar; agricultural waste; biodiesel production; sustainability; renewable energy

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1. Introduction

The global demand for energy continues to rise, driven by population growth and industrialization. Fossil fuels, which dominate the energy sector, are associated with greenhouse gas emissions, environmental degradation, and resource depletion. Biodiesel, a renewable energy source derived from organic materials, has gained significant attention as a sustainable alternative. While traditional biodiesel feedstocks, such as edible oils, pose concerns of food versus fuel competition, agricultural waste offers an untapped resource for biodiesel production. Agricultural waste comprises a wide range of residues generated during crop cultivation, harvesting, and processing. These include lignocellulosic biomass, fruit and vegetable peels, seed husks, and animal by-products. Utilizing these materials not only mitigates waste disposal issues but also contributes to circular economy principles by converting waste into value-added products. This paper aims to provide a comprehensive overview of the processes, challenges, and potential of using agricultural waste for biodiesel production. Energy plays a critical role in meeting the demands of the world and its inhabitants ((Kusuma et al., 2024, Gielen et al., 2019). The global energy landscape continues to rely heavily on fossil fuels such as crude oil, natural gas, and coal (Awogbemi and Von Kallon, 2023a). Despite their environmental drawbacks and diminishing reserves, fossil fuels remain dominant in the energy sector (Gielen et al., 2019). These resources, being finite, have been central to industrialized economies since the 1920s, with oil particularly serving as their backbone ((Kusuma et al., 2024, Guliyev and Mustafayev, 2022). As a result, research and development in sustainable renewable energy sources have become an urgent priority (Li et al., 2023). Renewable energy innovations are increasingly recognized as essential for addressing both energy shortages and global warming (Xu and Lin, 2023). Efforts to solve energy and environmental challenges are closely tied to the issue of underutilized agricultural waste (Babu et al., 2022). Agricultural waste can be transformed into renewable energy through methods like gasification, fermentation, and pyrolysis (Mlonka-Mędrala et al., 2021; Wang and Cheng, 2024). Among the various types of agricultural waste, rice straw waste is particularly notable. Rice, a staple food globally, is predominantly cultivated in Asia, which accounts for over 90% of the world's production. Southeast Asian countries, including Thailand, Myanmar, Vietnam, and Indonesia, contribute nearly 85% of the annual rice output (Silva et al., 2022). Indonesia, as one of the top three rice producers globally, has recently come close to achieving self-sufficiency in rice production (Agus et al., 2019). The cultivation of rice generates approximately 700 million tons of rice straw annually, posing challenges for its effective management (Siluk et al., 2023). Often, rice straw is burned as a method of disposal, but this practice creates significant environmental issues ((Kusuma et al., 2024, Propper et al., 2023; Singh et al., 2024). Biodiesel has emerged as a promising alternative fuel, recognized for its technological advancements in mitigating the environmental impacts associated with non-renewable energy production (Reshad et al., 2017). The dwindling supply of fossil fuels and their adverse environmental effects underscore the urgent need for renewable and eco-friendly energy solutions (Parida et al., 2022). Biodiesel, in particular, is gaining widespread acceptance as a sustainable and environmentally friendly fuel alternative (Jung et al., 2018). Many nations have introduced biofuel policies aimed at fostering environmental sustainability, which is critical for scaling up large-scale biodiesel production (Siddique, 2008; Yadav et al., 2023). In modern society, addressing the dual challenge of clean energy demand and global waste management requires innovative strategies. Access to energy is a key development indicator and significantly influences quality of life (Awogbemi and Von Kallon, 2023a). However, reliance on fossil fuels continues to harm ecosystems by releasing harmful atmospheric emissions (Pourhashem et al., 2019). Biochar, a carbon-rich solid material, has emerged as a valuable catalyst for enhancing biodiesel production efficiency (Velusamy et al., 2021). Utilizing biochar as a catalyst offers multiple advantages, including cost-effectiveness, sustainability, and environmental benefits (Wang et al., 2019). Biochar-based heterogeneous catalysts can be classified into acid and alkaline categories, providing diverse applications in biodiesel production (Rajendran et al., 2022). Despite its potential, there is limited awareness regarding the use of agricultural waste for biochar production and its benefits in biodiesel production. To bridge this knowledge gap, bibliometric analysis is being employed to explore research trends in biochar applications for biodiesel production from 2009 to March 12, 2024. This analysis aims to highlight the importance of converting agricultural waste into sustainable energy sources. It also investigates global research trends, country-level contributions, and collaborative research patterns in this vital field. The global demand for energy continues to rise, driven by population growth and industrialization. Fossil fuels, which dominate the energy sector, are associated with greenhouse gas emissions, environmental degradation, and resource depletion. Biodiesel, a renewable energy source derived from organic materials, has gained significant attention as a sustainable alternative. While traditional biodiesel feedstocks, such as edible oils, pose concerns of food versus fuel competition, agricultural waste offers an untapped resource for biodiesel production. Agricultural waste comprises a wide range of residues generated during crop cultivation, harvesting, and processing. These include lignocellulosic biomass, fruit and vegetable peels, seed husks, and animal by-products. Utilizing these materials not only mitigates waste disposal issues but also contributes to circular economy principles by converting waste into value-added products. This paper aims to provide a comprehensive overview of the processes, challenges, and potential of using agricultural waste for biodiesel production.

2. Historical Development

The concept of harnessing agricultural waste for sustainable biodiesel production has evolved significantly over the years, driven by the need for alternative energy sources and effective waste management. Early research in the mid-20th century focused primarily on exploring renewable energy sources to reduce dependence on fossil fuels. However, the utilization of agricultural waste as a raw material for biodiesel production gained momentum in the late 20th century, with advancements in biomass conversion technologies such as pyrolysis and transesterification. These techniques laid the foundation for transforming agricultural residues, like rice husks, corn cobs, and wheat straw, into value-added products, addressing both energy and environmental challenges .By the early 2000s, the integration of biochar as a catalyst in biodiesel production emerged as a breakthrough innovation. This shift was fueled by the recognition of biochar's high porosity, large surface area, and catalytic efficiency, which enhanced biodiesel yields while promoting sustainability (Borthakur et al., 2021). Concurrently, the development of heterogeneous catalysts derived from agricultural waste introduced new possibilities for cost-effective and environmentally friendly biodiesel production (Borthakur & Medhi, 2023). Governments and industries began implementing biofuel policies, providing subsidies and incentives to foster the use of agricultural residues as feedstocks. In recent decades, technological advancements have refined the processes of agricultural waste conversion and biodiesel synthesis. Biochar modifications, including surface and chemical enhancements, have significantly improved its catalytic properties, making biodiesel production more efficient (Borthakur et al., 2022). Furthermore, integrated biorefineries have emerged, enabling the simultaneous production of biodiesel and other bio-based products, thus enhancing economic feasibility. Today, the field is characterized by a strong focus on sustainability, with research emphasizing the dual benefits of mitigating agricultural waste management issues and reducing greenhouse gas emissions (Saikia et al., 2024). Global collaborations, policy interventions, and community engagement are driving the adoption of these technologies at scale, positioning agricultural waste as a cornerstone of the renewable energy revolution and a viable pathway toward a sustainable future

3. Production of Biochar

3.1. Agricultural Waste

Agricultural waste refers to the byproducts generated through various agricultural processes (Nagendran, 2011). These wastes include a wide array of organic materials such as plant residues, animal waste, and other agro-industrial byproducts. Examples include crop residues, forestry residues, logging remains, animal waste, jute fiber, bagasse, straw, chaff, and agricultural wastewater (Khedulkar et al., 2023; Periyasamy et al., 2024; Gontard et al., 2018). Table 3 categorizes these waste types in detail. The composition of agricultural waste varies, with starch accounting for the largest share at approximately 38%, followed by shells and husks (23%), wood (18%), grass (3%), mixed residues (6%), and other types (12%) (Karim et al., 2022). Annually, agricultural waste is estimated to reach about 998 million tons globally and is expected to increase due to insufficient waste management practices (Bhuvaneshwari et al., 2019; Obi et al., 2016). Major contributors include rice husks (100–120 million tons), corn cobs (200–230 million tons), bagasse (279–300 million tons), and wheat straw (400–529 million tons) (Periyasamy et al., 2024). Inefficient management practices, such as open-field burning, exacerbate environmental degradation and health risks (Patel and Panwar, 2023; Phiri et al., 2024). Furthermore, the lack of advanced waste management technologies compounds the problem. To mitigate these impacts, converting agricultural waste into useful products like **biochar** has emerged as a sustainable and economical solution (Koul et al., 2022; Ouyang et al., 2023). Biochar is a carbon-rich material produced through the thermal decomposition of organic matter under anaerobic conditions (Bian et al., 2024). The process is simple, cost-effective, and does not require complex infrastructure (Awogbemi and Von Kallon, 2023a). The resulting biochar possesses properties like high porosity and surface area, making it useful in applications such as agriculture, soil restoration, and waste management (Yu et al., 2023). Moreover, biochar exhibits significant adsorption capabilities, effectively removing contaminants from wastewater and mitigating greenhouse gas emissions (Awogbemi and Von Kallon, 2023b; Wang et al., 2023a).

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3.2. Characterization of Biochar Produced and Methods Used

The composition and characteristics of biochar depend significantly on the raw materials and production methods utilized (Ottani et al., 2023; Thakur et al., 2023). Agricultural waste composition influences the quality, cost, and efficiency of biochar production. Table 4 highlights various agricultural wastes analyzed for their biochar characteristics using diverse methods. One of the most common methods for biochar production is **pyrolysis**, where organic material is thermally decomposed in the absence of oxygen. This method, studied extensively by researchers such as Geng et al. (2021), Quesada et al. (2021), and Sreenivas et al. (2014), involves heating biomass at temperatures ranging from 300 to 800 °C under anaerobic conditions. For example, walnut shells subjected to pyrolysis at 500 °C with a heating rate of 8 °C per minute demonstrated the efficiency of this technique (Geng et al., 2021; Lin et al., 2024). Table 5 provides a detailed classification of pyrolysis technologies used in biochar production. In conclusion, sustainable management of agricultural waste through biochar production offers a promising solution to environmental and waste management challenges. The pyrolysis method, among other techniques, holds great potential for converting agricultural residues into valuable resources, contributing to a more sustainable and environmentally friendly future. Further optimization of processes and innovative technologies will be key to maximizing the benefits of biochar production.

4. Biodiesel Production from Biochar

Technological advancements and efficient utilization of resources have paved the way for innovative applications of biochar. Its unique properties, including chemical inertness, high functionality, structural stability, mechanical robustness, and thermal resistance, make biochar a versatile material (Awogbemi and Kallon, 2024; Melo et al., 2024). Additionally, biochar's high porosity, large specific surface area, and negative charge contribute to its effectiveness in diverse applications (Balajii and Niju, 2019). Beyond its environmental benefits and availability, biochar has been utilized as a catalyst, catalyst support material (Melo et al., 2024), electrode material in supercapacitors (Yusuff and Owolabi, 2019), adsorbent in carbon sequestration and storage (Melo et al., 2024), and a remediation agent for water and soil (Balajii and Niju, 2019).

One of the most promising applications of biochar is as a catalyst in the transesterification reaction for biodiesel production. Researchers have successfully modified biochar to function as an effective heterogeneous acid catalyst, enhancing biodiesel synthesis (Dehkhoda et al., 2010). Biochar-derived catalyst supports are cost-effective, environmentally friendly, and readily available, contributing to increased efficiency in biodiesel production. Key factors such as catalyst type, concentration, and reaction conditions significantly influence biodiesel yield (Awogbemi and Von Kallon, 2023a, 2023b). Heterogeneous catalysts, which are easier to separate and reusable, offer distinct advantages over homogeneous catalysts in biodiesel production. Specifically, metal oxide-based catalysts like CaO, MgO, ZnO, and $CaZrO_3$ derived from agricultural waste and crop residues have shown promising results (Awogbemi and Von Kallon, 2023a, 2023b). Furthermore, biochar modifications—including surface modification, porosity enhancement, chemical treatment, and physical alterations—have been employed to optimize its catalytic properties for biodiesel synthesis. Table 7 highlights the work of various researchers who have leveraged biochar as a catalyst in biodiesel production. The biodiesel yield generally increases with extended reaction times, although the optimal duration varies based on factors such as feedstock type, catalyst characteristics, and concentration (Salam et al., 2016). Nanoparticle properties, including activity, also play a crucial role in determining biodiesel production efficiency. This demonstrates the potential of biochar as a sustainable and economically viable catalyst for biodiesel synthesis, aligning with global efforts to develop renewable energy solutions and reduce dependency on fossil fuels. Further research and innovation in biochar applications are essential to fully realize its potential in biodiesel production

5. Feedstock for Biodiesel Production

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Agricultural residues offer an abundant and diverse pool of raw materials for biodiesel synthesis. Common agricultural waste materials include:

1. **Crop Residues**: Straw, stalks, and husks from crops like wheat, rice, and corn are rich in lignocellulosic biomass, which can be processed into biofuels.
2. **Fruit and Vegetable Waste**: Peels, seeds, and pomace from fruits such as oranges, bananas, and tomatoes are rich in lipids and other bioactive compounds suitable for biodiesel production.
3. **Animal Waste**: Fats and oils derived from slaughterhouse by-products provide high lipid content for biodiesel synthesis.
4. **Non-Edible Oilseeds**: Jatropha, Pongamia, and other non-edible seeds offer potential for biodiesel production without affecting food security.

The variability in composition and availability of these feedstocks necessitates tailored approaches to optimize their conversion into biodiesel.

Conversion Technologies

The transformation of agricultural waste into biodiesel involves several key processes, each with its technological advancements and challenges:

1. **Lipid Extraction**: Efficient extraction of lipids from agricultural waste is crucial. Methods include:
   - **Mechanical Extraction**: Simple and cost-effective but may result in lower yields.
   - **Chemical Solvent Extraction**: Utilizes solvents like hexane to achieve higher lipid recovery but raises concerns of toxicity and cost.
   - **Green Extraction Techniques**: Innovations like supercritical CO2 and ultrasonic-assisted extraction offer eco-friendly alternatives.
2. **Transesterification**: The extracted lipids undergo transesterification, where triglycerides react with alcohol (e.g., methanol) in the presence of a catalyst to produce biodiesel. Catalysts include:
   - **Homogeneous Catalysts**: Widely used but require rigorous purification processes.
   - **Heterogeneous Catalysts**: Easier to separate and recycle, contributing to cleaner production.
   - **Enzymatic Catalysis**: Offers high specificity and milder reaction conditions, though costs remain a limitation.
3. **Pretreatment of Feedstock**: Agricultural waste often contains impurities and water content that can inhibit biodiesel production. Pretreatment methods, such as drying, grinding, and chemical treatments, are employed to enhance feedstock quality.
4. **Biochemical Conversion**: Advanced processes, such as microbial fermentation and enzymatic hydrolysis, convert lignocellulosic biomass into biodiesel precursors. This approach is particularly suitable for non-lipid-rich feedstocks.

Environmental and Socio-Economic Impacts

Utilizing agricultural waste for biodiesel production offers numerous environmental and socio-economic benefits:

1. **Waste Management**: By diverting agricultural residues from landfills and open burning, this approach reduces air pollution and greenhouse gas emissions.
2. **Renewable Energy Generation**: Biodiesel derived from agricultural waste contributes to the global transition towards renewable energy sources, reducing dependence on fossil fuels.
3. **Rural Development**: Establishing biodiesel production units in rural areas promotes local employment and economic growth by creating value-added products from waste.
4. **Carbon Footprint Reduction**: Life cycle assessments indicate that biodiesel from agricultural waste has a significantly lower carbon footprint compared to petroleum-based fuels.

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5. **Energy Security**: Diversifying energy sources enhances national energy security, particularly in regions reliant on energy imports.

Challenges and Limitations

Despite its potential, agricultural waste-based biodiesel production faces several challenges:

1. **Feedstock Collection and Logistics**: Agricultural waste is often dispersed across large areas, complicating its collection and transportation.
2. **Technological Barriers**: High costs of advanced extraction and conversion technologies hinder widespread adoption.
3. **Economic Viability**: Fluctuations in feedstock availability and market prices for biodiesel affect profitability.
4. **Policy and Regulatory Support**: Lack of supportive policies and incentives limits investment in biodiesel projects.
5. **Quality Standards**: Ensuring consistent quality of biodiesel derived from heterogeneous feedstocks remains a challenge(Borthakur & Sarmah, 2013; Sarmah & Borthakur, 2013)..

6. Future Perspectives

To effectively address the challenges and fully harness the potential of agricultural waste for biodiesel production, a multifaceted approach is essential. **Technological innovation** stands at the forefront, with a pressing need for research and development of cost-effective and efficient conversion technologies. Advancements in pyrolysis, fermentation, and catalytic processes are crucial to optimizing the transformation of agricultural residues into biochar and biodiesel. Simultaneously, the establishment of **integrated biorefineries** offers a promising avenue to improve economic feasibility. By producing multiple products such as biodiesel, bioethanol, and biogas within a single facility, biorefineries can diversify revenue streams and increase the overall efficiency of resource utilization. **Public-private partnerships** can serve as a powerful driver of progress by fostering collaboration between governments, industries, and research institutions. These alliances can stimulate investments, expedite the development of cutting-edge technologies, and bridge the gap between research outcomes and large-scale commercial applications. Complementing these efforts, **policy interventions** by governments can create a conducive environment for waste-based biodiesel production. Offering tax incentives, subsidies, and grants for innovative waste-to-energy projects can motivate stakeholders to invest in and adopt sustainable practices. Equally important is **community engagement**, which involves educating farmers and local populations about the environmental and economic benefits of utilizing agricultural waste. Awareness campaigns, training programs, and financial incentives can encourage the collection and supply of agricultural residues as feedstock for biodiesel production. A bibliometric study analyzing publication trends, global research contributions, keyword usage, and authorship networks highlights the evolving research landscape of biochar and its role in biodiesel production. Biochar derived from agricultural biomass has gained significant attention for its versatility, particularly as a catalyst in biodiesel production (Thakur et al., 2023). The production process involves the pyrolysis and activation of biochar under controlled conditions, with recent research focusing on developing biochar-based catalysts for this application (Jayaraju et al., 2022). Looking forward, utilizing agricultural waste for biochar production in biodiesel manufacturing holds substantial promise. Agricultural residues, such as rice husks and sugarcane by-products, can be transformed into biochar, providing both economic benefits and opportunities for sustainable energy development. Technological advancements in this field are expected to further improve the efficiency and sustainability of biodiesel production, making the process more environmentally friendly (Babadi et al., 2022). Using biochar as a renewable catalyst not only reduces greenhouse gas emissions and mitigates climate change impacts but also lowers the carbon footprint associated with biodiesel production (Zhang et al., 2019b). Moreover, the integration of biochar into biodiesel manufacturing decreases reliance on finite fossil resources and addresses agricultural waste management challenges, transforming waste into a valuable resource (Patel and Panwar, 2023).

Despite the evident benefits and potential applications, further research is essential to optimize biochar production processes and fully realize its potential in biodiesel production. As research progresses, the future of biochar utilization in biodiesel production appears both promising and impactful.

7. Conclusions

Harnessing agricultural waste for biodiesel production presents a sustainable and innovative solution to address global energy demands, environmental challenges, and waste management issues. This approach leverages the abundant availability of agricultural residues, such as crop husks, fruit peels, and other organic by-products, to produce renewable energy, aligning with global efforts to reduce reliance on fossil fuels and mitigate climate change. Central to this strategy is the use of **biochar**, a carbon-rich material derived from biomass, which serves as a highly efficient and environmentally friendly catalyst in biodiesel production. The unique properties of biochar, including its high porosity, large surface area, and chemical stability, make it an invaluable resource in enhancing the efficiency and sustainability of biodiesel synthesis processes. This review underscores the socio-economic benefits of agricultural waste utilization, including waste valorization, rural development, and contributions to the circular economy. Furthermore, integrating biochar into these systems provides a dual advantage of improving biodiesel production efficiency and offering practical solutions for waste management. Despite these benefits, challenges remain, including feedstock variability, logistics of agricultural waste collection, and the need for technological and economic optimization of biochar production and modification processes.

Policy interventions, such as subsidies, tax incentives, and research funding, are essential to create an enabling environment for large-scale adoption of agricultural waste-based biodiesel production. Community engagement and awareness campaigns are equally critical to mobilize farmers and local stakeholders in providing reliable feedstock supplies. In conclusion, the integration of agricultural waste and biochar into biodiesel production systems offers a promising pathway toward a sustainable energy future. With continued advancements in technology, supportive policy frameworks, and global collaborations, this approach has the potential to significantly reduce environmental impacts, enhance energy security, and contribute to the achievement of sustainable development goals. The future of biodiesel production lies in unlocking the full potential of agricultural waste and biochar as key resources.

References

1 Kusuma, H. S., Az-Zahra, K. D., Saputri, R. W., Utomo, M. D. P., Jaya, D. E. C., Amenaghawon, A. N., & Darmokoesoemo, H. (2024). Unlocking the potential of agricultural waste as biochar for sustainable biodiesel production: A comprehensive review. *Bioresource Technology Reports*, *26*, 101848. https://doi.org/10.1016/j.biteb.2024.101848

2 Abdelwahab, S. I., Taha, M. M. E., Moni, S. S., & Alsayegh, A. A. (2023). Bibliometric mapping of solid lipid nanoparticles research (2012–2022) using VOSviewer. Medicine in Novel Technology and Devices, 17, 100217. https://doi.org/10.1016/j.medntd.2023.100217

3 Abdoulmoumine, N., Adhikari, S., Kulkarni, A., & Chattanathan, S. (2015). A review on biomass gasification syngas cleanup. Applied Energy, 155, 294–307. https://doi.org/10.1016/j.apenergy.2015.05.095

4 Aghel, B., Behaein, S., & Alobaid, F. (2022). CO2 capture from biogas by biomass-based adsorbents: A review. Fuel, 328, 125276. https://doi.org/10.1016/j.fuel.2022.125276

5 Agus, F., Andrade, J. F., Rattalino Edreira, J. I., Deng, N., Purwantomo, D. K. G., Agustiani, N., Aristya, V. E., Batubara, S. F., Herniwati, Hosang, E. Y., Krisnadi, L. Y., Makka, A., Samijan, Cenacchi, N., Wiebe, K., & Grassini, P. (2019). Yield gaps in intensive rice-maize cropping sequences in the humid tropics of Indonesia. Field Crops Research, 237, 12–22. https://doi.org/10.1016/j.fcr.2019.04.006

6 Akinfalabi, S.-I., Rashid, U., Ngamcharussrivichai, C., & Nehdi, I. A. (2020). Synthesis of reusable biobased nano-catalyst from waste sugarcane bagasse for biodiesel production. Environmental Technology & Innovation, 18, 100788. https://doi.org/10.1016/j.eti.2020.100788

7 Amalina, F., Razak, A. S. A., Krishnan, S., Sulaiman, H., Zularisam, A. W., & Nasrullah, M. (2022). Biochar production techniques utilizing biomass waste-derived materials and environmental applications: A review. Journal of Hazardous Materials Advances, 7, 100134. https://doi.org/10.1016/j.hazadv.2022.100134

8 Sarmah, P., & Borthakur, P. P. (2013). Comparison of Jatropha biodiesel with pure diesel: An approach for alternative and environmental friendly energy resource. *International Journal of Engineering Research & Technology (IJERT), 2*(10), 719–736.

9 Borthakur, P. P., & Medhi, N. (2023). Green revolution: Promising feedstock for sustainable biodiesel production. *European Chemical Bulletin, 12*(10), 2306–2325.

10 Saikia, M., Sarmah, P., & Borthakur, P. P. (2024). A review of challenges to adoption of biodiesel as a diesel substitute in India. *Renewable Energy Research and Applications, 5*(2), 221–227.

11 Anand, A., Kumar, V., & Kaushal, P. (2022a). Biochar and its twin benefits: Crop residue management and climate change mitigation in India. Renewable and Sustainable Energy Reviews, 156, 111959. https://doi.org/10.1016/j.rser.2021.111959

12 Anand, A., Pathak, S., Kumar, V., & Kaushal, P. (2022b). Biochar production from crop residues, its characterization and utilization for electricity generation in India. Journal of Cleaner Production, 368, 133074. https://doi.org/10.1016/j.jclepro.2022.133074

13 Avhad, M. R., & Marchetti, J. M. (2015). A review on recent advancement in catalytic materials for biodiesel production. Renewable and Sustainable Energy Reviews, 50, 696–718. https://doi.org/10.1016/j.rser.2015.05.038

14 Awogbemi, O., & Kallon, D. V. V. (2024). Recent advances in the application of nanomaterials for improved biodiesel, biogas, biohydrogen, and bioethanol production. Fuel, 358, 130261. https://doi.org/10.1016/j.fuel.2023.130261

15 Awogbemi, O., & Von Kallon, D. V. (2023a). Application of biochar derived from crops residues for biofuel production. Fuel Communications, 15, 100088. https://doi.org/10.1016/j.jfueco.2023.100088

16 Awogbemi, O., & Von Kallon, D. V. (2023b). Progress in agricultural waste derived biochar as adsorbents for wastewater treatment. Applied Surface Science Advances, 18, 100518. https://doi.org/10.1016/j.apsadv.2023.100518

17 Babadi, A. A., Rahmati, S., Fakhlaei, R., Barati, B., Wang, S., Doherty, W., & Ostrikov, K. (Ken). (2022). Emerging technologies for biodiesel production: Processes, challenges, and opportunities. Biomass and Bioenergy, 163, 106521. https://doi.org/10.1016/j.biombioe.2022.106521

18 Babu, S., Rathore, S. S., Singh, R., Kumar, S., Singh, V. K., Yadav, S. K., Yadav, V., Raj, R., Yadav, D., Shekhawat, K., & Wani, O. A. (2022). Exploring agricultural waste biomass for energy, food, and feed production and pollution mitigation: A review. Bioresource Technology, 360, 127566. https://doi.org/10.1016/j.biortech.2022.127566

19 Bach, Q.-V., Chen, W.-H., Lin, S.-C., Sheen, H.-K., & Chang, J.-S. (2017). Wet torrefaction of microalga Chlorella vulgaris ESP-31 with microwave-assisted heating. Energy Conversion and Management, 141, 163–170. https://doi.org/10.1016/j.enconman.2016.07.035

20 Badoei-Dalfard, A., Karami, Z., & Malekabadi, S. (2019). Construction of CLEAs-lipase on magnetic graphene oxide nanocomposite: An efficient nanobiocatalyst for biodiesel production. Bioresource Technology, 278, 473–476. https://doi.org/10.1016/j.biortech.2019.01.050

21 Balajii, M., & Niju, S. (2019). Biochar-derived heterogeneous catalysts for biodiesel production. *Environmental Chemistry Letters, 17*(4), 1447–1469. https://doi.org/10.1007/s10311-019-00885-x

22 Behera, B., Selvam, S. M., Dey, B., & Balasubramanian, P. (2020). Algal biodiesel production with engineered biochar as a heterogeneous solid acid catalyst. *Bioresource Technology, 310,* 123392. https://doi.org/10.1016/j.biortech.2020.123392

23 Benjamin, M. F. D., Ventura, J.-R. S., Sangalang, K. P. H., Adorna, J. A., Belmonte, B. A., & Andiappan, V. (2021). Optimal synthesis of Philippine agricultural residue-based integrated biorefinery via the P-graph

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 6 January 2025 doi:10.20944/preprints202501.0348.v1

method under supply and demand constraints. *Journal of Cleaner Production, 308,* 127348. https://doi.org/10.1016/j.jclepro.2021.127348

24 Bergman, E. M. L. (2012). Finding citations to social work literature: The relative benefits of using Web of Science, Scopus, or Google Scholar. *The Journal of Academic Librarianship, 38*(6), 370–379. https://doi.org/10.1016/j.acalib.2012.08.002

25 Bhatia, S. C. (2014). Biodiesel. In *Advanced Renewable Energy Systems* (pp. 573–626). Elsevier. https://doi.org/10.1016/B978-1-78242-269-3.50022-X

26 Bhatia, S. K., Gurav, R., Choi, T.-R., Kim, H. J., Yang, S.-Y., Song, H.-S., Park, J. Y., Park, Y.-L., Han, Y.-H., Choi, Y.-K., Kim, S.-H., Yoon, J.-J., & Yang, Y.-H. (2020). Conversion of waste cooking oil into biodiesel using heterogeneous catalyst derived from cork biochar. *Bioresource Technology, 302,* 122872. https://doi.org/10.1016/j.biortech.2020.122872

27 Bhuvaneshwari, S., Hettiarachchi, H., & Meegoda, J. (2019). Crop residue burning in India: Policy challenges and potential solutions. *International Journal of Environmental Research and Public Health, 16*(5), 832. https://doi.org/10.3390/ijerph16050832

28 Bian, X., Ren, Z., Zeng, L., Zhao, F., Yao, Y., & Li, X. (2024). Effects of biochar on the compressibility of soil with high water content. *Journal of Cleaner Production, 434,* 140032. https://doi.org/10.1016/j.jclepro.2023.140032

29 Borthakur, P. P., Sarma, G., Hazarika, H., Bhattacharyya, S., & Hazarika, T. (2021). Microalgae *Asterarcys* sp.: A potential source for biodiesel production. *Indian Journal of Natural Sciences, 12*(69), 35547–35555.

30 Bibi, A., Naz, S., & Uroos, M. (2021). Evaluating the effect of ionic liquid on biosorption potential of peanut waste: Experimental and theoretical studies. *ACS Omega, 6*(36), 22259–22271. https://doi.org/10.1021/acsomega.1c02957

31 Boraah, N., Chakma, S., & Kaushal, P. (2022). Attributes of wood biochar as an efficient adsorbent for remediating heavy metals and emerging contaminants from water: A critical review and bibliometric analysis. *Journal of Environmental Chemical Engineering, 10*(6), 107825. https://doi.org/10.1016/j.jece.2022.107825

32 Cao, M., Lu, M., Yin, H., Zhu, Q., Xing, K., & Ji, J. (2023). Effect of hemicellulose extraction pretreatment on sulfonated corncob biochar for catalytic biodiesel production. *Journal of Environmental Chemical Engineering, 11,* 109058. https://doi.org/10.1016/j.jece.2022.109058

33 Chen, X., Chen, G., Chen, L., Chen, Y., Lehmann, J., McBride, M. B., & Hay, A. G. (2011). Adsorption of copper and zinc by biochars produced from pyrolysis of hardwood and corn straw in aqueous solution. *Bioresource Technology, 102*(19), 8877–8884. https://doi.org/10.1016/j.biortech.2011.06.078

34 Chen, W.-H., Huang, M.-Y., Chang, J.-S., & Chen, C.-Y. (2014). Thermal decomposition dynamics and severity of microalgae residues in torrefaction. *Bioresource Technology, 169,* 258–264. https://doi.org/10.1016/j.biortech.2014.06.086

35 Borthakur, P. P., Sarmah, P., Biswakarma, K., & Talukdar, A. (2022). An overview of microalgae for the production of biodiesel. *International Journal of Mechanical Engineering, 7*(1), 2848–2853.

36 Chen, W.-H., Huang, M.-Y., Chang, J.-S., & Chen, C.-Y. (2015). Torrefaction operation and optimization of microalgae residue for energy densification and utilization. *Applied Energy, 154,* 622–630. https://doi.org/10.1016/j.apenergy.2015.05.068

37 Chilakamarry, C. R., Khilji, I. A., Sirohi, R., Pandey, A., Baskar, G., & Satyavolu, J. (2023). Maximizing the value of biodiesel industry waste: Exploring recover, recycle, and reuse for sustainable environment. *Environmental Technology & Innovation, 32,* 103447. https://doi.org/10.1016/j.eti.2023.103447

38 Cho, S.-H., Lee, D.-J., Kim, J. Y., Choi, Y.-B., Park, S., Park, J., Kim, J. K., Kim, H., Jung, S., & Kwon, E. E. (2024). Valorization of cattle manure via a thermo-chemical process. *Chemical Engineering Journal, 479,* 147911. https://doi.org/10.1016/j.cej.2023.147911

39 Cuadrado-Osorio, P. D., Ramírez-Mejía, J. M., Mejía-Avellaneda, L. F., Mesa, L., & Bautista, E. J. (2022). Agro-industrial residues for microbial bioproducts: A key booster for bioeconomy. *Bioresource Technology Reports, 20,* 101232. https://doi.org/10.1016/j.biteb.2022.101232

40 Balajii, M., & Niju, S. (2019). Biochar-derived heterogeneous catalysts for biodiesel production. *Environmental Chemistry Letters, 17*(4), 1447–1469. https://doi.org/10.1007/s10311-019-00885-x

41 Behera, B., Selvam, S. M., Dey, B., & Balasubramanian, P. (2020). Algal biodiesel production with engineered biochar as a heterogeneous solid acid catalyst. *Bioresource Technology, 310,* 123392. https://doi.org/10.1016/j.biortech.2020.123392

42 Benjamin, M. F. D., Ventura, J.-R. S., Sangalang, K. P. H., Adorna, J. A., Belmonte, B. A., & Andiappan, V. (2021). Optimal synthesis of Philippine agricultural residue-based integrated biorefinery via the P-graph method under supply and demand constraints. *Journal of Cleaner Production, 308,* 127348. https://doi.org/10.1016/j.jclepro.2021.127348

43 Bergman, E. M. L. (2012). Finding citations to social work literature: The relative benefits of using Web of Science, Scopus, or Google Scholar. *The Journal of Academic Librarianship, 38*(6), 370–379. https://doi.org/10.1016/j.acalib.2012.08.002

44 Bhatia, S. C. (2014). Biodiesel. In *Advanced Renewable Energy Systems* (pp. 573–626). Elsevier. https://doi.org/10.1016/B978-1-78242-269-3.50022-X

45 Bhatia, S. K., Gurav, R., Choi, T.-R., Kim, H. J., Yang, S.-Y., Song, H.-S., Park, J. Y., Park, Y.-L., Han, Y.-H., Choi, Y.-K., Kim, S.-H., Yoon, J.-J., & Yang, Y.-H. (2020). Conversion of waste cooking oil into biodiesel using heterogeneous catalyst derived from cork biochar. *Bioresource Technology, 302,* 122872. https://doi.org/10.1016/j.biortech.2020.122872

46 Bhuvaneshwari, S., Hettiarachchi, H., & Meegoda, J. (2019). Crop residue burning in India: Policy challenges and potential solutions. *International Journal of Environmental Research and Public Health, 16*(5), 832. https://doi.org/10.3390/ijerph16050832

47 Bian, X., Ren, Z., Zeng, L., Zhao, F., Yao, Y., & Li, X. (2024). Effects of biochar on the compressibility of soil with high water content. *Journal of Cleaner Production, 434,* 140032. https://doi.org/10.1016/j.jclepro.2023.140032

48 Bibi, A., Naz, S., & Uroos, M. (2021). Evaluating the effect of ionic liquid on biosorption potential of peanut waste: Experimental and theoretical studies. *ACS Omega, 6*(36), 22259–22271. https://doi.org/10.1021/acsomega.1c02957

49 Boraah, N., Chakma, S., & Kaushal, P. (2022). Attributes of wood biochar as an efficient adsorbent for remediating heavy metals and emerging contaminants from water: A critical review and bibliometric analysis. *Journal of Environmental Chemical Engineering, 10*(6), 107825. https://doi.org/10.1016/j.jece.2022.107825

50 Cao, M., Lu, M., Yin, H., Zhu, Q., Xing, K., & Ji, J. (2023). Effect of hemicellulose extraction pretreatment on sulfonated corncob biochar for catalytic biodiesel production. *Journal of Environmental Chemical Engineering, 11,* 109058. https://doi.org/10.1016/j.jece.2022.109058

51 Chen, X., Chen, G., Chen, L., Chen, Y., Lehmann, J., McBride, M. B., & Hay, A. G. (2011). Adsorption of copper and zinc by biochars produced from pyrolysis of hardwood and corn straw in aqueous solution. *Bioresource Technology, 102*(19), 8877–8884. https://doi.org/10.1016/j.biortech.2011.06.078

52 Chen, W.-H., Huang, M.-Y., Chang, J.-S., & Chen, C.-Y. (2014). Thermal decomposition dynamics and severity of microalgae residues in torrefaction. *Bioresource Technology, 169,* 258–264. https://doi.org/10.1016/j.biortech.2014.06.086

53 Chen, W.-H., Huang, M.-Y., Chang, J.-S., & Chen, C.-Y. (2015). Torrefaction operation and optimization of microalgae residue for energy densification and utilization. *Applied Energy, 154,* 622–630. https://doi.org/10.1016/j.apenergy.2015.05.068

54 Chilakamarry, C. R., Khilji, I. A., Sirohi, R., Pandey, A., Baskar, G., & Satyavolu, J. (2023). Maximizing the value of biodiesel industry waste: Exploring recover, recycle, and reuse for sustainable environment. *Environmental Technology & Innovation, 32,* 103447. https://doi.org/10.1016/j.eti.2023.103447

55 Cho, S.-H., Lee, D.-J., Kim, J. Y., Choi, Y.-B., Park, S., Park, J., Kim, J. K., Kim, H., Jung, S., & Kwon, E. E. (2024). Valorization of cattle manure via a thermo-chemical process. *Chemical Engineering Journal, 479,* 147911. https://doi.org/10.1016/j.cej.2023.147911

56 Cuadrado-Osorio, P. D., Ramírez-Mejía, J. M., Mejía-Avellaneda, L. F., Mesa, L., & Bautista, E. J. (2022). Agro-industrial residues for microbial bioproducts: A key booster for bioeconomy. *Bioresource Technology Reports, 20,* 101232. https://doi.org/10.1016/j.biteb.2022.101232

57 Dahman, Y., Syed, K., Begum, S., Roy, P., & Mohtasebi, B. (2019). Biofuels. In *Biomass, Biopolymer-based Materials, and Bioenergy* (pp. 277–325). Elsevier. https://doi.org/10.1016/B978-0-08-102426-3.00014-X

58 Daimary, N., Eldiehy, K. S. H., Boruah, P., Deka, D., Bora, U., & Kakati, B. K. (2022). Potato peels as a sustainable source for biochar, bio-oil, and a green heterogeneous catalyst for biodiesel production. *Journal of Environmental Chemical Engineering, 10*. https://doi.org/10.1016/j.jece.2021.107108

59 Dehkhoda, A. M., West, A. H., & Ellis, N. (2010). Biochar-based solid acid catalyst for biodiesel production. *Applied Catalysis A: General, 382*(1–2), 197–204. https://doi.org/10.1016/j.apcata.2010.04.051

60 Domingues, R. R., Trugilho, P. F., Silva, C. A., de Melo, I. C. N. A., Melo, L. C. A., Magriotis, Z. M., & Sánchez-Monedero, M. A. (2017). Properties of biochar derived from wood and high-nutrient biomasses with the aim of agronomic and environmental benefits. *PLOS ONE, 12*(5), e0176884. https://doi.org/10.1371/journal.pone.0176884

61 Dong, T., Gao, D., Miao, C., Yu, X., Degan, C., Garcia-Pérez, M., Rasco, B., Sablani, S. S., & Chen, S. (2015). Two-step microalgal biodiesel production using acidic catalyst generated from pyrolysis-derived bio-char. *Energy Conversion and Management, 105*, 1389–1396. https://doi.org/10.1016/j.enconman.2015.06.072

62 Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research, 133*, 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

63 Duque-Acevedo, M., Belmonte-Ureña, L. J., Cortés-García, F. J., & Camacho-Ferre, F. (2020). Agricultural waste: Review of the evolution, approaches, and perspectives on alternative uses. *Global Ecology and Conservation, 22*, e00902. https://doi.org/10.1016/j.gecco.2020.e00902

64 Enaime, G., Baçaoui, A., Yaacoubi, A., & Lübken, M. (2020). Biochar for wastewater treatment—conversion technologies and applications. *Applied Sciences, 10*(10), 3492. https://doi.org/10.3390/app10103492

65 Fernández, J. V., Faria, D. N., Santoro, M. C., Mantovaneli, R., Cipriano, D. F., Brito, G. M., Carneiro, M. T. W. D., Schettino, M. A., Gonzalez, J. L., & Freitas, J. C. C. (2023). Use of unmodified coffee husk biochar and ashes as heterogeneous catalysts in biodiesel synthesis. *Bioenergy Research, 16*(6), 1746–1757. https://doi.org/10.1007/s12155-022-10516-z

66 Freudenmann, D., Wolf, S., Wolff, M., & Feldmann, C. (2011). Ionic liquids: New perspectives for inorganic synthesis? *Angewandte Chemie International Edition, 50*(47), 11050–11060. https://doi.org/10.1002/anie.201100904

67 Fu, T., Ke, J. H., Zhou, S., & Xie, G. H. (2020). Estimation of the quantity and availability of forestry residue for bioenergy production in China. *Resources, Conservation and Recycling, 162,* 104993. https://doi.org/10.1016/j.resconrec.2020.104993

68 G, G., S, K., R, Y. K., Bhatia, S. K., S, A. K., M, R., Kumar, G., Pugazhendhi, A., Chi, N. T. L., & J, R. B. (2021). Valorization of agricultural residues: Different biorefinery routes. *Journal of Environmental Chemical Engineering, 9*(4), 105435. https://doi.org/10.1016/j.jece.2021.105435

69 Gardy, J., Osatiashtiani, A., Céspedes, O., Hassanpour, A., Lai, X., Lee, A. F., Wilson, K., & Rehan, M. (2018). A magnetically separable SO4/Fe-Al-TiO2 solid acid catalyst for biodiesel production from waste cooking oil. *Applied Catalysis B: Environmental, 234,* 268–278. https://doi.org/10.1016/j.apcatb.2018.04.046

70 Geng, X., Lv, S., Yang, J., Cui, S., & Zhao, Z. (2021). Carboxyl-functionalized biochar derived from walnut shells with enhanced aqueous adsorption of sulfonamide antibiotics. *Journal of Environmental Management, 280,* 111749. https://doi.org/10.1016/j.jenvman.2020.111749

71 Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., & Gorini, R. (2019). The role of renewable energy in the global energy transformation. *Energy Strategy Reviews, 24,* 38–50. https://doi.org/10.1016/j.esr.2019.01.006

72 Gontard, N., Sonesson, U., Birkved, M., Majone, M., Bolzonella, D., Celli, A., Angellier-Coussy, H., Jang, G.-W., Verniquet, A., Broeze, J., Schaer, B., Batista, A. P., & Sebok, A. (2018). A research challenge vision regarding management of agricultural waste in a circular bio-based economy. *Critical Reviews in Environmental Science and Technology, 48*(7–9), 614–654. https://doi.org/10.1080/10643389.2018.1471957

73 Borthakur, P. P., & Sarmah, P. (2013). Performance analysis of blends of Jatropha biodiesel. *International Journal of Scientific & Engineering Research, 4*(1).

74 González, M. E., Cea, M., Reyes, D., Romero-Hermoso, L., Hidalgo, P., Meier, S., Benito, N., & Navia, R. (2017). Functionalization of biochar derived from lignocellulosic biomass using microwave technology for catalytic application in biodiesel production. *Energy Conversion and Management, 137,* 165–173. https://doi.org/10.1016/j.enconman.2017.01.063

75 Guler, A. T., Waaijer, C. J. F., Mohammed, Y., & Palmblad, M. (2016). Automating bibliometric analyses using Taverna scientific workflows: A tutorial on integrating web services. *Journal of Informetrics, 10*(4), 830–841. https://doi.org/10.1016/j.joi.2016.05.002

76 Guliyev, H., & Mustafayev, E. (2022). Predicting the changes in the WTI crude oil price dynamics using machine learning models. *Resources Policy, 77,* 102664. https://doi.org/10.1016/j.resourpol.2022.102664

77 Harisankar, S., Francis Prashanth, P., Nallasivam, J., Vishnu Mohan, R., & Vinu, R. (2021). Effects of aqueous phase recirculation on product yields and quality from hydrothermal liquefaction of rice straw. *Bioresource Technology, 342,* 125951. https://doi.org/10.1016/j.biortech.2021.125951

78 Hebbar, H. R. H., Math, M. C., & Yatish, K. V. (2018). Optimization and kinetic study of CaO nanoparticles catalyzed biodiesel production from Bombax ceiba oil. *Energy, 143,* 25–34. https://doi.org/10.1016/j.energy.2017.10.118

79 Hu, B., Liu, J., Xie, W., Li, Y., & Lu, Q. (2024). Biofuels production using pyrolysis techniques. In *Advances in Biofuels Production, Optimization, and Applications* (pp. 103–125). Elsevier. https://doi.org/10.1016/B978-0-323-95076-3.00010-7

80 Jain, N., & Sharma, M. (2021). Evaluation of acute dermal toxicity of *Cymbopogon martinii* leaves essential oil in Swiss albino mice. *Journal of Essential Oil-Bearing Plants, 24*(2), 342–348. https://doi.org/10.1080/0972060X.2021.1915185

81 Jayaraju, R. M., Gaddam, K., Ravindiran, G., Palani, S., Paulraj, M. P., Achuthan, A., Saravanan, P., & Muniasamy, S. K. (2022). Biochar from waste biomass as a biocatalyst for biodiesel production: An overview. *Applied Nanoscience, 12,* 3665–3676. https://doi.org/10.1007/s13204-021-01924-2

82 Jung, J.-M., Oh, J.-I., Baek, K., Lee, J., & Kwon, E. E. (2018). Biodiesel production from waste cooking oil using biochar derived from chicken manure as a porous media and catalyst. *Energy Conversion and Management, 165,* 628–633. https://doi.org/10.1016/j.enconman.2018.03.096

83 Karim, A. A., Kumar, M., Singh, E., Kumar, A., Kumar, S., Ray, A., & Dhal, N. K. (2022). Enrichment of primary macronutrients in biochar for sustainable agriculture: A review. *Critical Reviews in Environmental Science and Technology, 52*(12), 1449–1490. https://doi.org/10.1080/10643389.2020.1859271

84 Keenum, A., & Shubrook, J. (2012). How to peer review a scientific or scholarly article. *Osteopathic Family Physician, 4*(4), 176–179. https://doi.org/10.1016/j.osfp.2012.06.003

85 Khan, S. A., Rashmi, Hussain, M. Z., Prasad, S., & Banerjee, U. C. (2009). Prospects of biodiesel production from microalgae in India. *Renewable and Sustainable Energy Reviews, 13*(9), 2361–2372. https://doi.org/10.1016/j.rser.2009.04.005

86 Khan, N., Chowdhary, P., Ahmad, A., Shekher Giri, B., & Chaturvedi, P. (2020). Hydrothermal liquefaction of rice husk and cow dung in Mixed-Bed-Rotating Pyrolyzer and application of biochar for dye removal. *Bioresource Technology, 309,* 123294. https://doi.org/10.1016/j.biortech.2020.123294

87 Khedulkar, A. P., Pandit, B., Dang, V. D., & Doong, R. (2023). Agricultural waste to real worth biochar as a sustainable material for supercapacitor. *Science of the Total Environment, 869,* 161441. https://doi.org/10.1016/j.scitotenv.2023.161441

88 Knothe, G. (2010). Biodiesel and renewable diesel: A comparison. *Progress in Energy and Combustion Science, 36*(3), 364–373. https://doi.org/10.1016/j.pecs.2009.11.004

89 Korkut, I., & Bayramoglu, M. (2018). Selection of catalyst and reaction conditions for ultrasound-assisted biodiesel production from canola oil. *Renewable Energy, 116,* 543–551. https://doi.org/10.1016/j.renene.2017.10.010

90 Koul, B., Yakoob, M., & Shah, M. P. (2022). Agricultural waste management strategies for environmental sustainability. *Environmental Research, 206,* 112285. https://doi.org/10.1016/j.envres.2021.112285

91 Li, W., & Zhao, Y. (2015). Bibliometric analysis of global environmental assessment research in a 20-year period. *Environmental Impact Assessment Review, 50,* 158–166. https://doi.org/10.1016/j.eiar.2014.09.012

92 Li, Y., Wang, X., Imran, A., Aslam, M. U., & Mehmood, U. (2023). Analyzing the contribution of renewable energy and natural resources for sustainability in G-20 countries: How gross capital formation impacts ecological footprints. *Heliyon, 9,* e18882. https://doi.org/10.1016/j.heliyon.2023.e18882

93 Liang, X., Zeng, M., & Qi, C. (2010). One-step synthesis of carbon functionalized with sulfonic acid groups using hydrothermal carbonization. *Carbon, 48,* 1844–1848. https://doi.org/10.1016/j.carbon.2010.01.030

94 Lin, J., Xu, Z., Zhang, Q., Cao, Y., Mašek, O., Lei, H., & Tsang, D. C. W. (2024). Enhanced adsorption of aromatic VOCs on hydrophobic porous biochar produced via microwave rapid pyrolysis. *Bioresource Technology, 393,* 130085. https://doi.org/10.1016/j.biortech.2023.130085

95 Liu, S., Jiang, J., Yin, M., Zheng, Y., Wang, C., & Yan, L. (2023). Promoting performance of Anammox by iron-loaded sludge biochar with hydrothermal carbonization (HTC-Fe-BC) addition. *Process Safety and Environmental Protection, 170,* 596–607. https://doi.org/10.1016/j.psep.2022.12.032

96 Lyu, H., Lim, J. Y., Zhang, Q., Senadheera, S. S., Zhang, C., Huang, Q., & Ok, Y. S. (2024). Conversion of organic solid waste into energy and functional materials using biochar catalyst: Bibliometric analysis, research progress, and directions. *Applied Catalysis B: Environmental, 340,* 123223. https://doi.org/10.1016/j.apcatb.2023.123223

97 Madeira, J. V., Contesini, F. J., Calzado, F., Rubio, M. V., Zubieta, M. P., Lopes, D. B., & de Melo, R. R. (2017). Agro-industrial residues and microbial enzymes. In *Biotechnology of Microbial Enzymes* (pp. 475–511). Elsevier. https://doi.org/10.1016/B978-0-12-803725-6.00018-2

98 Mansir, N., Teo, S. H., Rashid, U., & Taufiq-Yap, Y. H. (2018). Efficient waste *Gallus domesticus* shell-derived calcium-based catalyst for biodiesel production. *Fuel, 211,* 67–75. https://doi.org/10.1016/j.fuel.2017.09.014

99 Markscheffel, B., & Schröter, F. (2021). Comparison of two science mapping tools based on software technical evaluation and bibliometric case studies. *Collnet Journal of Scientometrics and Information Management, 15,* 365–396. https://doi.org/10.1080/09737766.2021.1960220

100 McAllister, J. T., Lennertz, L., & Atencio Mojica, Z. (2022). Mapping a discipline: A guide to using VOSviewer for bibliometric and visual analysis. *Science & Technology Libraries, 41,* 319–348. https://doi.org/10.1080/0194262X.2021.1991547

101 Megía, P. J., Vizcaíno, A. J., Calles, J. A., & Carrero, A. (2021). Hydrogen production technologies: From fossil fuels toward renewable sources. A mini review. *Energy & Fuels, 35,* 16403–16415. https://doi.org/10.1021/acs.energyfuels.1c02501

102 Meho, L. I. (2019). Using Scopus's CiteScore for assessing the quality of computer science conferences. *Journal of Informetrics, 13,* 419–433. https://doi.org/10.1016/j.joi.2019.02.006

103 Melo, V. M. E., Ferreira, G. F., & Fregolente, L. V. (2024). Sustainable catalysts for biodiesel production: The potential of CaO supported on sugarcane bagasse biochar. *Renewable and Sustainable Energy Reviews, 189,* 114042. https://doi.org/10.1016/j.rser.2023.114042

104 Mlonka-Mędrala, A., Evangelopoulos, P., Sieradzka, M., Zajemska, M., & Magdziarz, A. (2021). Pyrolysis of agricultural waste biomass towards production of gas fuel and high-quality char: Experimental and numerical investigations. *Fuel, 296,* 120611. https://doi.org/10.1016/j.fuel.2021.120611

105 Nagendran, R. (2011). Agricultural waste and pollution. In *Waste* (pp. 341–355). Elsevier. https://doi.org/10.1016/B978-0-12-381475-3.10024-5

106 Nidheesh, P. V., Gopinath, A., Ranjith, N., Praveen Akre, A., Sreedharan, V., & Suresh Kumar, M. (2021). Potential role of biochar in advanced oxidation processes: A sustainable approach. *Chemical Engineering Journal, 405,* 126582. https://doi.org/10.1016/j.cej.2020.126582

107 Nielsen, K. S., Nicholas, K. A., Creutzig, F., Dietz, T., & Stern, P. C. (2021). The role of high-socioeconomic-status people in locking in or rapidly reducing energy-driven greenhouse gas emissions. *Nature Energy, 6,* 1011–1016. https://doi.org/10.1038/s41560-021-00900-y

108 Obi, F. O., Ugwuishiwu, B. O., & Nwakaire, J. N. (2016). Agricultural waste concept, generation, utilization and management. *Nigerian Journal of Technology, 35,* 957. https://doi.org/10.4314/njt.v35i4.34

109 Ottani, F., Morselli, N., De Luca, A., Puglia, M., Pedrazzi, S., & Allesina, G. (2023). The conductivity dilemma: How biochar grain's chemical composition and morphology hinder the direct measurement of its electrical conductivity. *Measurement, 222,* 113662. https://doi.org/10.1016/j.measurement.2023.113662

110 Ouyang, H., Safaeipour, N., Othman, R. S., Otadi, M., Sheibani, R., Kargaran, F., Van Le, Q., Khonakdar, H. A., & Li, C. (2023). Agricultural waste-derived (nano)materials for water and wastewater treatment: Current challenges and future perspectives. *Journal of Cleaner Production, 421,* 138524. https://doi.org/10.1016/j.jclepro.2023.138524

111 Parida, S., Singh, M., & Pradhan, S. (2022). Biomass wastes: A potential catalyst source for biodiesel production. *Bioresource Technology Reports, 18,* 101081. https://doi.org/10.1016/j.biteb.2022.101081

112 Patel, M. R., & Panwar, N. L. (2023). Biochar from agricultural crop residues: Environmental, production, and life cycle assessment overview. *Resources, Conservation, and Recycling Advances, 19,* 200173. https://doi.org/10.1016/j.rcradv.2023.200173

113 Periyasamy, S., Asefa Adego, A., Kumar, P. S., Desta, G. G., Zelalem, T., Karthik, V., Isabel, J. B., Jayakumar, M., Sundramurthy, V. P., & Rangasamy, G. (2024). Influencing factors and environmental feasibility analysis of agricultural waste preprocessing routes towards biofuel production – A review. *Biomass and Bioenergy, 180,* 107001. https://doi.org/10.1016/j.biombioe.2023.107001

114 Phiri, R., Mavinkere Rangappa, S., & Siengchin, S. (2024). Agro-waste for renewable and sustainable green production: A review. *Journal of Cleaner Production, 434,* 139989. https://doi.org/10.1016/j.jclepro.2023.139989

115 Potnuri, R., Surya, D. V., Rao, C. S., Yadav, A., Sridevi, V., & Remya, N. (2023). A review on analysis of biochar produced from microwave-assisted pyrolysis of agricultural waste biomass. *Journal of Analytical and Applied Pyrolysis, 173,* 106094. https://doi.org/10.1016/j.jaap.2023.106094

116 Pourhashem, G., Hung, S. Y., Medlock, K. B., & Masiello, C. A. (2019). Policy support for biochar: Review and recommendations. GCB Bioenergy, 11(4), 364–380. https://doi.org/10.1111/gcbb.12582

117 Price, D. D. S. (1976). A general theory of bibliometric and other cumulative advantage processes. Journal of the American Society for Information Science, 27(5), 292–306. https://doi.org/10.1002/asi.4630270505

118 Propper, C. R., Sedlock, J. L., Smedley, R. E., Frith, O., Shuman-Goodier, M. E., Grajal-Puche, A., Stuart, A. M., & Singleton, G. R. (2023). Balancing food security, vertebrate biodiversity, and healthy rice agroecosystems in Southeast Asia. Crop and Environment. https://doi.org/10.1016/j.crope.2023.11.005

119 Pydimalla, M., Husaini, S., Kadire, A., & Kumar Verma, R. (2023). Sustainable biodiesel: A comprehensive review on feedstock, production methods, applications, challenges, and opportunities. Materials Today: Proceedings, 92, 458–464. https://doi.org/10.1016/j.matpr.2023.03.593

120 Quah, R. V., Tan, Y. H., Mubarak, N. M., Kansedo, J., Khalid, M., Abdullah, E. C., & Abdullah, M. O. (2020). Magnetic biochar derived from waste palm kernel shell for biodiesel production via sulfonation. Waste Management, 118, 626–636. https://doi.org/10.1016/j.wasman.2020.09.016

121 Quesada, H. B., de Araújo, T. P., Cusioli, L. F., de Barros, M. A. S. D., Gomes, R. G., & Bergamasco, R. (2021). Evaluation of novel activated carbons from chichá-do-cerrado (Sterculia striata St. Hil. et Naud) fruit shells on metformin adsorption and treatment of a synthetic mixture. Journal of Environmental Chemical Engineering, 9, Article 104914. https://doi.org/10.1016/j.jece.2020.104914

122 Rajendran, N., Kang, D., Han, J., & Gurunathan, B. (2022). Process optimization, economic and environmental analysis of biodiesel production from food waste using a citrus fruit peel biochar catalyst. Journal of Cleaner Production, 365. https://doi.org/10.1016/j.jclepro.2022.132712

123 Reshad, A. S., Panjiara, D., Tiwari, P., & Goud, V. V. (2017). Two-step process for production of methyl ester from rubber seed oil using barium hydroxide octahydrate catalyst: Process optimization. Journal of Cleaner Production, 142, 3490–3499. https://doi.org/10.1016/j.jclepro.2016.10.118

124 Rogovski, P., Cadamuro, R. D., Marques Souza, D. S., Savi, B. P., Razzzolini, M. T. P., de Souza Lauretto, M., Sato, M. I. Z., Nardocci, A. C., Júnior, S. L. A., Treichel, H., & Fongaro, G. (2022). Animal residues use and application for sustainable agriculture on one health approach. In New and Future Developments in Microbial Biotechnology and Bioengineering (pp. 131–158). Elsevier. https://doi.org/10.1016/B978-0-323-85579-2.00013-7

125 Rubini, L., Pollio, C., Barbieri, E., & Cattaruzzo, S. (2024). Changing structures in transnational research networks: An analysis of the impact of COVID-19 on China's scientific collaborations. Structural Change and Economic Dynamics, 69, 281–297. https://doi.org/10.1016/j.strueco.2023.12.018

126 Sakina, A., Nazir, N., Sultan, P., & Hassan, Q. P. (2023). Bioconversion of agricultural residues and waste to value-added products. In Value-Addition in Agri-Food Industry Waste Through Enzyme Technology (pp. 355–364). Elsevier. https://doi.org/10.1016/B978-0-323-89928-4.00015-8
127 Salam, K. A., Velasquez-Orta, S. B., & Harvey, A. P. (2016). A sustainable integrated in situ transesterification of microalgae for biodiesel production and associated co-product: A review. Renewable and Sustainable Energy Reviews, 65, 1179–1198. https://doi.org/10.1016/j.rser.2016.07.068
128 Salleh, Z. M., Yahya, N. Y., Nasarudin, M. A. S., & Herman, D. N. (2022). Transesterification of used frying oil by activated banana peels waste catalyst for biodiesel production. Materials Today: Proceedings, 57, 1235–1240. https://doi.org/10.1016/j.matpr.2021.11.074
129 Shah, M. A., Khan, N. S., Kumar, V., & Qurashi, A. (2021). Pyrolysis of walnut shell residues in a fixed bed reactor: Effects of process parameters, chemical and functional properties of bio-oil. Journal of Environmental Chemical Engineering, 9, Article 105564. https://doi.org/10.1016/j.jece.2021.105564
130 Shelare, S. D., Belkhode, P. N., Nikam, K. C., Jathar, L. D., Shahapurkar, K., Soudagar, M. E. M., Veza, I., Khan, T. M. Y., Kalam, M. A., Nizami, A.-S., & Rehan, M. (2023). Biofuels for a sustainable future: Examining the role of nano-additives, economics, policy, Internet of Things, artificial intelligence, and machine learning technology in biodiesel production. Energy, 282, Article 128874. https://doi.org/10.1016/j.energy.2023.128874
131 Siddique, R. (2008). Rice husk ash. In Waste Materials and By-Products in Concrete (pp. 235–264). Springer. https://doi.org/10.1007/978-3-540-74294-4_7
132 Sikarwar, V. S., Zhao, M., Fennell, P. S., Shah, N., & Anthony, E. J. (2017). Progress in biofuel production from gasification. Progress in Energy and Combustion Science, 61, 189–248. https://doi.org/10.1016/j.pecs.2017.04.001
133 Siluk, J. C. M., de Carvalho, P. S., Thomasi, V., Pappis, C. A. de O., & Schaefer, J. L. (2023). Cloud-based energy management systems: Terminologies, concepts, and definitions. Energy Research & Social Science, 106, Article 103313. https://doi.org/10.1016/j.erss.2023.103313
134 Silva, J. V., Pede, V. O., Radanielson, A. M., Kodama, W., Duarte, A., de Guia, A. H., Malabayabas, A. J. B., Pustika, A. B., Argosubekti, N., Vithoonjit, D., Hieu, P. T. M., Pame, A. R. P., Singleton, G. R., & Stuart, A. M. (2022). Revisiting yield gaps and the scope for sustainable intensification for irrigated lowland rice in Southeast Asia. Agricultural Systems, 198, Article 103383. https://doi.org/10.1016/j.agsy.2022.103383
135 Singh, Y., Sharma, S., Kumar, U., Sihag, P., Balyan, P., Singh, K. P., & Dhankher, O. P. (2024). Strategies for economic utilization of rice straw residues into value-added by-products and prevention of environmental pollution. Science of the Total Environment, 906, Article 167714. https://doi.org/10.1016/j.scitotenv.2023.167714
136 Smith, S. A., & Duncan, A. A. (2022). Systematic and scoping reviews: A comparison and overview. Seminars in Vascular Surgery, 35, 464–469. https://doi.org/10.1053/j.semvascsurg.2022.09.001
137 Su, M., Peng, H., & Li, S. (2021). A visualized bibliometric analysis of mapping research trends of machine learning in engineering (MLE). *Expert Systems with Applications, 186*, 115728. https://doi.org/10.1016/j.eswa.2021.115728
138 Suárez, L., Benavente-Ferraces, I., Plaza, C., de Pascual-Teresa, S., Suárez-Ruiz, I., & Centeno, T. A. (2020). Hydrothermal carbonization as a sustainable strategy for integral valorization of apple waste. *Bioresource Technology*, *309*, 123395. https://doi.org/10.1016/j.biortech.2020.123395
139 Thakur, A. K., Kumar, R., Shukla, P., Sharma, P., & Kulabhi, A. (2023). Biochar from agricultural biomass: Current status and future scope. *Materials Today: Proceedings.* https://doi.org/10.1016/j.matpr.2023.05.209