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Editorial: Technoeconomic analysis of integrated biorefinery approaches through process system engineering

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Editorial on the Research Topic
Technoeconomic analysis of integrated biorefinery approaches through process system engineering

In this Editorial, we focused on the critical research needs in developing biorefineries and adopting value chain analysis on an industrial scale. To offer a more structured view of our Research Topic, we have categorized the research into three key thematic areas: resources, conversion technology, and evaluation. This arrangement intends to guide readers logically by identifying bio-resources, the various techniques to transform these resources, and assessing their efficiency and economy.

We accepted experimental and computational work with process optimization techniques, such as embedded biorefinery approaches through machine learning, life cycle evaluation, and techno-economical elements, to investigate the market potential and development strategies, which will be much valued. At the same time, thermochemical processes such as pyrolysis, gasification, liquefaction, and fermentation were used to convert waste into valuable products. The Research Topic also endorsed various pure research articles about bioenergy generation for clean energy generation and process optimization to obtain useful chemicals and products.

First, we addressed the potential of various resources to act as feedstock for biorefineries. A representative study in this category is "Green Electricity Generation from Biogas". This study tackled the environmental concern of organic waste incineration and garbage disposal in several countries by exploring the biogas generation from cow and buffalo dung in Pakistan. The study outlined how this approach can mitigate global warming while providing a renewable energy source. This solution is a clear example of how biowaste can be efficiently utilized as a resource for bioenergy generation. Next, we examined several conversion technologies that can turn these resources into valuable products. One such conversion method was thermochemical processes like pyrolysis, gasification, liquefaction, and fermentation. A notable study is "Waste to Product through TG-FTIR-MS,"

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which recovered phenolic components cost-effectively from Cabbage Waste (CW). Another conversion technology highlighted was bacterial consortia, as shown in “Role of Bacterial Consortium”. This study used a bacterial consortium and surfactant to detoxify or immobilize crude oil-contaminated soil. It shows the potential to use microorganisms as a bio augmentation tool in soil remediation.

Finally, we explored the critical assessment methods used to evaluate these bio-refineries, including their efficiency, economic viability, and environmental impact. “Techno economic Analysis of Biomass” typified this theme by investigating the connection between technological criteria and economic viability in the pyrolysis of diverse biomass for producing sustainable bio-oils. It concluded that understanding the interplay of cost, capacity, and biomass type is crucial for realizing market compatibility and enhancing the commercial viability of bio-oil facilities. In addition, a study like “Variation of Maringa Olefiera L in different Maturity Stages” helped bridge all three thematic areas. It identified a potential bio-resource (Maringa Oleifera leaves), studied how their nutritional and antioxidant profile varied with maturity (conversion), and recommended optimal harvesting periods for maximizing their functional food and nutricosmetic benefits (evaluation).

Green Electricity Generation from Biogas: Because of organic waste incineration and garbage disposal, organic or municipal solid wastes, such as cow and buffalo dung, have become a severe environmental concern in several countries. Biogas generation from manure is a green solution that helps the availability of renewable energy and aids in mitigating global warming to address this Research Topic. Pakistan's production of renewable energy from cow and buffalo excrement was the subject of the current study. In 2021, Pakistan produced 102,742 (TWh) of energy; biogas contributed 0.98%, or roughly 1 TWh, to this total. Unfortunately, most of the electricity was derived from non-renewable energy sources. A big animal produces 9, 10 kg of dung every day. For manure Research Topic, it is possible to build a system to collect 30% of the dung produced daily by cattle and buffalo. A system of this type is already in operation for collecting chicken manure. Pakistan is endowed with close to 42.4 million buffaloes and 51.5 million animals. At a rate of 30%, the amount of manure collected annually from cattle and buffalo will be 92.53 million tonnes. This manure may create around 4.63 billion m^3 of biogas, of which 3.24 billion m^3 are recoverable. Therefore, Pakistan can generate 19.79 (TWh) power per year from cow and buffalo excrement. Biogas can provide approximately 20% of Pakistan's total power. At the farm level, 100 cow ranches with 60% collected dung may generate around 57% of their total power consumption. Slurry, the product of anaerobic digestion, can be utilized as a biofertilizer in fields. Biogas, “Produced by the fermentation of organic waste in the absence of oxygen,” may be produced using cattle dung. Reducing greenhouse gas emissions contributes to reducing reliance on fossil fuels, managing solid waste, and controlling air pollution. Biogas contributes to all three pillars of sustainable development: economic growth, environmental development, and social development. Biogas contributes substantially to sustainability and other elements of sustainable development (SDDs).

Waste to Product through TG-FTIR-MS: This study revealed the recovery of the phenolic components through TG-FTIR analysis cost-effectively for optimizing the temperature-associated profiles. At different temperature ranges from (400°C–600°C), TG-FTIR and Py/GC-MS analysis of Cabbage Waste (CW) was performed to detect the chemical and understand the material concentration's nature. The energy production for 1 kg CW of liquid product was 9.78 MJ/kg, suggesting 3.23 MJ/kg loss. After comparative chemical analysis, it was determined that TG-FTIR is an efficient and cost-effective method for optimizing pyrolysis temperature for the thermochemical conversion of biomass with enhanced recovery of phenol contents from CW.

Variation of *Moringa oleifera* L in different Maturity Stages: This study revealed variation in the nutritional and antioxidant profile of *Moringa oleifera* leaves in four stages of adulthood (October to January). The highest yield and total phenolic contents (TPC) of 80% methanolic extract from *M. oleifera* leaves were reported to be 14.21% and 95.26 mg/g, respectively, during the early stage and 9.695% and 38.22 mg/g, during the latter stage. The contents of total flavonoids, ash, protein, vitamin C, and β-carotene were found to be lowest during the early stage and highest during the late stage, whereas Cu, Fe, and Mn levels in *M. oleifera* leaves at various stages of maturation ranged from 0.59 to 2.08, 21.96 to 58.68, and 5.56–13.84 mg/100 g, respectively. RP-HPLC analysis of the nutritionally dense later-stage leaves revealed quercetin as the most abundant constituent (21.64 mg/kg), followed by benzoic acid, ferulic acid, gallic acid, and p-coumaric acid with contributions of 13.03, 8.85, 3.39, 2.89, and 1.59 mg/kg, respectively. As *M. oleifera* leaves matured, a significant shift in the various nutrients and antioxidants profile was observed. These findings recommend harvesting *M. oleifera* leaves at the optimal maturity stage to optimize this valuable food item's functional food and nutricosmetic advantages.

Role of Bacterial Consortium: Crude oil is a significant polluter of aquatic and terrestrial ecosystems. Emerging technology phytoremediation includes the effective use of plant species to remove, detoxify, or immobilize soil toxins through natural processes. Inoculated with a previously identified and described bacterial consortia, Para grass (*Brach aria multicar*) was grown in a container containing crude oil-contaminated soil for this investigation. The effects of varying doses of non-ionic surfactant (Triton X-100) on the breakdown of crude oil in contaminated soil were detected (0.01%, 0.1%, and 1% of a 10% detergent solution in ultrapure water). After 4 months of study, the greatest root length (28.57 cm), shoot length (65.73 cm), and root and shoot dry biomass (92.42 g) were recorded in a container containing 0.1% surfactants and the bacterial consortium (T_7). Increasing the concentration of Triton X-100 from 0.01% to 1% with a bacterial consortium resulted in the greatest elimination of total petroleum hydrocarbons ranging from 6% to 40%. This indicates that Triton X-100 concentrations above 0.1% impede the development of plants. In addition, the FTIR study confirmed the hydrocarbon degradation, which can be attributed to the fact that the adopted plant species can degrade crude oil contamination. After 120 days of the experiment, the FTIR results show that different functional groups handle petroleum hydrocarbons in soil samples. The current study concludes that using an integrated treatment of crude oil-affected soil utilizing Triton X-100 and microorganisms can assist in restoring contaminated soils for agricultural use. Future solutions such as bio augmentation of polluted soil with PGPR and using genetically modified (GMO) plants may increase plant tolerance and reduce soil pollutant levels for improved soil health and increased crop output.

Technoeconomic Analysis of Biomass: The pyrolysis of biomass is one of the valuable sources for producing sustainable bio-oil. There are few commercially viable bio-oil facilities because of their complicated operations and poor revenues. It is essential to appreciate the connection between technological criteria and economic viability. This article describes the technological and economical procedure for producing bio-oils from diverse biomass using rapid pyrolysis. Cost, capacity, and biomass type were examined as specific indicators for bio-oil production. Bio-oil production costs are essential for determining market compatibility with other available biofuels. Various pre-treatments, improvements, and recycling methods affected production costs. It is feasible to produce bio-oil from biomass pyrolysis by employing an energy integration technique. This study's findings might inspire bio-oil industry-related research targeted at commercializing the product.

Author contributions

MA: Conceptualization, Methodology, Writing—Original Draft Preparation. AN: Supervision, Writing—Reviewing and Editing, Validation. BS: Data curation, Formal analysis, Visualization. AE: Project administration, Funding acquisition, Resources, Reviewing, and Editing. All authors contributed to the article and approved the submitted version.

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As Guest Editors, we would like to thank all contributing authors for making it possible to share their most recent research with the scientific community in this Research Topic. We particularly appreciate the Frontiers platform for offering such an opportunity for the active research community in this field to collate fascinating subjects in an organized manner. We hope this Research Topic of works can stimulate further research and discussion on the promising field of integrated biorefinery approaches and process system engineering.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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