Biorefining Technologies in the Global South

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ABSTRACT

The Global South faces a significant challenge in accessing clean and affordable energy due to underdevelopment. However, these regions possess abundant but underutilized biomass resources that can be converted into clean energy and valuable chemicals through bio-refining technologies. These technologies are gaining popularity worldwide as environmentally friendly alternatives to conventional petroleum-based industries, presenting viable paths for environmental sustainability, economic growth, and energy security in the Global South. This chapter reviews the bioenergy resources available with their total estimated potentials in the Global South. Savings estimate from improved stoves as well as the estimated number of biorefineries in the global south countries with their installed capacities were highlighted using comparative efficiency analysis. It also examines the socio-economic and environmental impacts of bio-refining activities in the Global South and outlines the way forward. Socioeconomic impacts analysis suggests that enabling policy frameworks, such as renewable energy targets, carbon pricing mechanisms, biofuel mandates, and research grants, are crucial to advancing the adoption and spread of bio-refinery technologies in the Global South. Ultimately, the sustainable development of the Global South through bio-refinery technologies offers opportunities for energy independence, economic diversification, and environmental preservation.

Keywords: Bio-refinery, technology, biomass, Global South, bioenergy.

INTRODUCTION

The quest for sustainable development coupled with mitigating climate change has necessitated the global shift towards renewable and environmentally sustainable alternatives across various industries. In the Global South, where the pursuit of economic growth is often intertwined with challenges of resource scarcity, energy insecurity, and environmental development, biorefinery technologies emerged as one of the promising solutions. It addresses these challenges by converting biomass resources into an array of products, including biofuels, useful chemicals, bioplastics, and other bio-based materials. Biorefinery is a physical facility that integrates biomass conversion processes and equipment to produce fuels, power, heat, and value-added chemicals from biomass feedstocks (Ferreira, 2017: Suhag and Sharma, 2015). In contrast to conventional refineries, which primarily process fossil fuels, biorefineries utilize a wide range of biomass such as forest residues, energy crops, agricultural residues, and organic wastes to produce a spectrum of products via chemical, biochemical, thermal, and biological conversion processes. However, the Global South refers collectively to countries and regions located in the southern hemisphere that share common socio-economic and developmental challenges (Kowalski, 2021; Chant and McIlwaine, 2009). It is often contrasted with more economically developed countries of the northern hemisphere called Global North (Kowalski, 2021). The Global South is characterized by a diverse range of cultures, languages, and historical experiences, but it is united by its position as the less economically developed and politically influential part of the world. Owing to the vast arable land and abundant biomass resources, in recent years, the Global South has witnessed a surge in bio-refinery initiatives, driven by a confluence of factors including abundant biomass resources, technological advancements, policy incentives, and growing market demand for sustainable products. These initiatives aim to harness the region's vast agricultural, forestry, and organic waste residues to produce value-added bio-based products while simultaneously mitigating environmental impacts associated with traditional industries. According to a report by the International Energy Agency (IEA), in 2020, there were approximately 100 commercial-scale biorefineries operating in the Global South, primarily concentrated in countries like Brazil, India, and Thailand (Singh et al., 2022). Brazil has been a pioneer in the biorefinery sector, with its well-established sugarcane industry serving as a foundation to produce bioethanol and other bio-based products (Gírio et al., 2017). While the Global South holds significant potential for biorefinery development, several challenges need to be addressed. Limited access to financing, inadequate infrastructure for biomass transportation and processing, and a lack of supportive policies and regulatory frameworks can hinder the growth of this sector. For instance, Brazil is a global leader in biofuel production, particularly ethanol from sugarcane (Gírio et al., 2017), it has successfully integrated biofuels into its transportation sector, reducing dependency on imported oil and contributing to rural development. Similarly, India has a robust biogas program that promotes the use of biogas digesters for rural cooking and decentralized electricity generation. The National Biogas and Manure Management Program (NBMMP) has installed thousands of biogas plants across the country (Sawale & Kulkarni, 2022). In Nigeria, the first biogas plant was constructed at the Usmanu Danfodiyo University in Sokoto in the 1980s with an installed biogas capacity of 425 liters per day (Akinbami et al., 2001). Subsequently, there was an increase in the number of biogas digesters constructed across the country. Nevertheless, owing to the large amount of organic waste generated annually (approximately 542.2 million tons), the number of installed digesters was not encouraging. Several factors, including a lack of sufficient processing expertise, and inadequate technology awareness, were reported to be responsible for the constraints (Biodun et al., 2021). It should be added that the deployment of biorefineries in these regions has been hindered by various factors, including infrastructural limitations, lack of investment, and policy uncertainties (Kowalski, 2021). This review is aimed at exploring the vast potentials of bioenergy resources available with their total estimates in the Global South. Savings estimate from improved stoves as well as the estimated number of biorefineries in the global south countries with their installed capacities were highlighted using comparative efficiency analysis taking into cognisance of various biorefining technologies with their social, economic, and environmental impacts.

BIOENERGY RESOURCES IN THE GLOBAL SOUTH

Bioenergy resources refer to those materials that are of biological origin such as forest and crop residues, animal wastes, and organic urban wastes that can be further processed and utilized in energy applications and the production of useful chemicals for domestic and industrial applications (Barot, 2022: Srivastava et al., 2021). Global South is blessed with a diverse range of renewable energy resources that play crucial roles in the energy mix of developing countries, offering opportunities for sustainable development, energy security, and rural livelihood improvement (Table 1). **Table 1** is an estimate of bioenergy that can be generated from various feedstock in the Global South. It also highlights the generation capacity of the abundant feedstock with their contributions to the global energy mix. Countries like Brazil, China, and India are reported to have much potential in terms of generation capacity and supply to the global energy mix (IEA, 2020: IRENA, 2021: FAO, 2024).

Table 1: Estimate of bioenergy generation potentials in the Global South

BIOENERGY	FEEDSTOCK	GENERATION CAPACITY	SUPPLY TO THE GLOBAL ENERGY MIX BY YEAR 2020	TOP PRODUCING COUNTRIES	SOURCE
Bioethanol	Sugar cane, sugar beet, corn, and other feedstocks	130 billion liters	53% with a CAGR of 10.5%	Brazil, Argentina, Thailand	IEA, FAO
Biogas	2.5 billion tons of biodegradable organic waste	30 billion cubic meters (m^3) of biomethane per year	34% with a CAGR of 12.1 %	China, India, and Brazil	IRENA, UNEP
Biodiesel	Vegetable oil	10 billion liters	2% with a CAGR of	Brazil,	IEA,

	from Oil-seed crops and animal fats.		9.5%	Indonesia	WWF
Bioelectricity	Biodegradable organic matter	150 GW	4% with a CAGR of 2%	Brazil, China, and India	IRENA, WWF

Types of Bioenergy Resources

Bioenergy resources can be categorized based on their source and the manner in which they are utilized for energy production. Here are the main types of bioenergy resources:

Dedicated Energy Crops: These are non-food crops that are grown on marginal lands with the aim of providing biomass. They consist of herbaceous crops (that can be harvested annually after taking 2 or 3 years before reaching their maturity stage. Examples of these include: miscantus, switchgrass, and sweet sorghum) and woody biomass (fast-growing trees that can be harvested after 5-8 years of planting. Examples; are cottonwood, sweetgum, and black walnut (Balaman, 2019).

Agricultural crop residues: these are the lignocellulosic agricultural products left on the fields after harvests. They include corn stover, wheat straw, rice straw, and oat straw (Davies et al., 2021). **Table 2** give an estimate of bioenergy resources potentials in the Global South with an amount in metric tons per year.

Forestry residues: These are small trees and branches that are left in forests after harvest operations (Badgujar & Bhanage, 2018). Examples include branches, roots, foliage, stumps, treetops, bark, and sawdust.

Algae: This is a diverse group of highly productive organisms that utilize sunlight and nutrients to produce lipids, proteins, and carbohydrates. These products can be converted and upgraded to fuels and useful chemicals. Examples; are microalgae, macroalgae, and cyanobacteria (Kumar et al., 2016).

Wet waste: These are food wastes, organic-rich biosolids, manure slurries, and organic wastes obtained from residential, commercial, and institutional operations. These waste materials can be converted to biogas- the gaseous product obtained from the anaerobic decomposition of organic waste material (Pangallo et al., 2023: Capodaglio & Callegari, 2023). Examples include animal dung, abattoir waste, kitchen waste, municipal solid waste, and industrial organic waste.

Table 2: Estimate of bioenergy resources potentials in the Global South

Bioenergy Resources	**Amount**	**Source**
1- Agricultural waste		
Crop residue	1.4 billion metric tons per year	FAO
Animal manure	2.3 billion metric tons per year	FAO
Food waste	1.3 billion metric tons per year	FAO
2- Energy crops		
Jatropha curcas	10 million hectares of plantable land available in Africa, Asia, and Latin America	IEA
Switch grass	100 million hectares of plantable land available in Africa, Asia, and Latin America	IEA
Sugar cane	250 million hectares of plantable land available in Africa, Asia, and Latin America	IEA

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3- Forestry residues	500 million metric tons per year	FAO
4- Municipal solid waste	1.5 billion metric tons per year	WORLD BANK
5- Algal biomass	100 million hectares of suitable land and water area	IEA
6- Waste water treatment potential from industrial processes	10 million metric tons per year	IEA

Benefits of Bioenergy Resources in the Global South

Bioenergy resources present numerous benefits for countries in the Global South, particularly in addressing energy access, economic development, and environmental sustainability. Here are some key advantages:

Energy Access: Bioenergy being a domestic resource in the global south, its utilization for transportation, industrial, and other domestic applications can provide significant access to energy thereby reducing the region's over-reliance on foreign oil. This can help to lower the cost of fuel as well as strengthen energy security (AM & S, 2023).

Sustainable Development: Utilising these resources in bioenergy production contributes to sustainable development by creating green jobs in manufacturing, agriculture, and other industries.

Waste Management and Climate Mitigation: the biodegradability of these resources coupled with their net-zero carbon-dioxide emission makes them clean resources for bioenergy production. Thus, utilisation of these resources does not add to the global atmospheric CO_2 as the amount of CO_2 released during the burning of biomass is offset by the amount of CO_2 absorbed by the plants. Similarly, some conversion routes of bioenergy resources are found to be CO_2-negative (Kalak, 2023: Shahbaz et al., 2021).

TYPES OF BIOENERGY

Bioenergy, derived from biological materials, can be broadly classified into traditional bioenergy and modern bioenergy. These two categories merely depend on distinct approaches to utilizing biomass for energy purposes, each with its own technological, environmental, and socio-economic implications.

Traditional Bioenergy

Traditional bioenergy refers to the traditional way of utilising biomass in such forms as wood, animal wastes, and charcoal for cooking, heating, and lighting across the countries in the Global South. It relies on age-old techniques and often involves inefficient combustion methods, such as open fires, mud stoves, three-stone fires, and rudimentary stoves. Traditional bioenergy is low-cost and does not require processing before use (Karekezi et al., 2012). However, this practice is responsible for a significant proportion of indoor air pollution consequent to respiratory diseases in many highland areas of the global south with women and children being the most vulnerable group in terms of biomass scarcity and adverse indoor air pollution (Karekezi et al., 2012). Some of these challenges posed by the application of traditional bioenergy could be properly addressed by the integration of improved biomass technologies (IBTs) that are found to be more efficient and environmentally friendly. For instance, different versions of improved burning stoves were designed and fabricated to enhance combustion efficiency, reduce heat loss, decrease indoor air pollution, and attain a higher heat transfer (Masera et al, 2000). This results in direct energy savings and by extension, cash savings (Table 3). **Table 3** provides savings estimate from charcoal in some selected Global South countries by using comparative efficiency analysis as reported in (Karekezi and Ranja, 1997; World Bank, 2003). Similarly, improved biomass technologies can help to reduce the burden of fuel collection by women and children which will translate to having more time for women to engage in other income-generating activities as well as increased time for education of rural children (Masera et al, 2000).

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Table 3: Savings estimate from improved stoves in some nations of the Global South

Daily charcoal consumption (kg per person per day)			Yearly savings per family (kg)	Value of savings ($)	GNP Per capita (US$)
	Traditional stove	Improved stove			
Kenya	0.67	0.39	64.70	613	350
Rwanda	0.51	0.33	84.10	394	22

Source: (Karekezi and Ranja, 1997; World Bank, 2003)

Modern Bioenergy

Modern bioenergy refers to the energy produced through the deployment of advanced technologies and processes in converting biomass into more efficient and sustainable forms. It encompasses a range of technologies aimed at improving energy efficiency, reducing emissions, and expanding the scope of bioenergy applications. Key forms of modern bioenergy include:

Biofuels: Liquid biofuels like biodiesel and ethanol are produced through advanced processes such as fermentation of sugars and transesterification of fats and vegetable oil. They can be used in transportation, industry, and power generation. These technologies have the potential to provide jobs to the teeming unemployed youth in the global south. For instance, Brazil produces 14 billion liters of bioethanol from sugarcane annually- responsible for creating 462,000 direct jobs and 1,386,000 indirect jobs in the country (Masera et al, 2000). Examples of feedstocks used in biodiesel production are vegetable oils extracted from oilseed crops such as; neem oil seeds, castor oil seeds, jatropha curcas oil-seeds, and animal fats. Bioethanol is produced through fermentation of sugars mainly obtained from sugarcane and sugar beet.

Biogas: Biogas is produced through the anaerobic digestion of organic materials such as agricultural residues, food wastes, and animal manure. It consists mainly of methane (53-60%) and carbon dioxide (39-43%) and can be used for cooking, heating, and electricity generation (Calbry-Muzyka et al., 2022). Biogas production helps in solving the menace of waste disposal and bio-waste management.

Advanced Combustion Technologies:

Technologies like biomass gasification and pyrolysis enable the conversion of biomass into heat, electricity, and fuels with higher efficiency and lower emissions compared to traditional methods

Challenges and Considerations

Biorefineries are facilities that convert biomass into a range of bio-based products, including biofuels, biochemicals, and other value-added materials. While they present significant opportunities for sustainable energy and resource utilization, several challenges and considerations impact their development and operation. Here are some key challenges:

Resource Competition: There is a serious risk of food versus energy competition especially when food crops are used for biofuel production. Experts in the field recommend the use of non-food crops and algae in bioenergy production (Kumar et al., 2023).

Technology and Infrastructure: Scaling up bioenergy projects requires adequate knowledge and technology transfer, infrastructure development, and investment in research and development (Bakhtiar et al., 2020).

Environmental Impacts: While bioenergy is generally considered sustainable, improper land use practices and inefficient technologies can lead to environmental degradation and loss of biodiversity (Souza et al., 2017).

Policy and Support Mechanisms

To scale up bioenergy production in the global south, Governments and international organizations need to play a critical role in promoting bioenergy through policy support, financial incentives, and capacity building. Policies often focus on improving energy efficiency, promoting sustainable agricultural practices, and supporting small-scale bioenergy projects (AM & S, 2023).

BIOREFINERY IN THE GLOBAL SOUTH

Biorefinery is a complex entity that depicts the range of industries that deal with biomass technology and has the ability to produce several industrial products and energy sources. In this regard, the concept of biorefinery focuses on a critical role in creating sustainable development in the Global South countries. Since the nations within this region face such challenges as energy insecurity, polluted environment, and economic decline, the concept of biorefinery could be seen as an effective strategy that fits the existing problems. Bio-refinery is identified as a complex sustainable development solution, which can utilize feedstocks of biomass resources like agricultural residue, forestry waste, or even dedicated energy crops (Kumar & Verma, 2021). Through the conversion of these renewable materials to biofuels, biochemicals, and biomaterials, biorefinery also affords a possibility of minimizing the dependence on fossil resources while at the same time driving resource efficiency and carbon cycle economy. Thus, energy security is still significant for most countries of the Global South because they still experience slow economic development and energy poverty. Biorefinery is therefore an opportunity to generate bioenergy within the countries, and thus decrease their reliance on external sources of fossil fuels and increase the sovereignty of the nation’s energy supply. Further, biorefineries could also act as catalysts to develop the various economies at the local level, boost employment, and independent technological evolution for sustainable economic growth. It is also evident that climate change mainly affects the Global South in the worst possible ways, meaning that greenhouse gas emissions must be addressed, and solutions must be found to the changes in climate occurring in the world today. In this regard, the concept of biorefinery will be a viable solution for providing bioenergy which is characterised by a rather low carbon intensity compared to the equivalents derived from the fossils. Furthermore, incorporating agricultural and forestry residues in biorefineries, pave the way for waste minimisation besides improving the soil quality and managing the practices for the lands. Most countries in the developing world of the Global South depend on agriculture and forestry as sources of their income. The inhabitants realised that biorefinery could contribute to the development of rural areas where the farmers and other members of the community could have another source of income from the utilisation of biomass resources. Likewise, the development of upstream bio-products and bioenergy can help to increase energy provision to the rural populace and other areas that are undeserved (Heijman et al., 2019). **Table 4** itemised the number of biorefineries with their installed capacities in the Global South. Out of the three regions, Asia is reported to have more number of biorefineries followed by Latin America with Africa having the least. Country wise, although Brazil has more number of biorefineries than China, the install capacity of China outweigh the Latin American countries combined IEA (2020).

Table 4: Estimated number of biorefineries in some of the Global South countries with their installed capacities.

Region	Country	Number of Biorefineries	Installed Capacity (Mmt/yr)
Asia	China	240	54.5
	India	140	12.3
	Indonesia	100	8.4
	Turkey	25	0.8
	Philippines	20	1.2
Africa	South Africa	20	1.3
	Egypt	10	0.5

	Nigeria	15	0.02
Latin America	Brazil	400	36.2
	Argentina	20	1.51
	Colombia	15	0.52
	Mexico	40	3

SOURCE: IEA (2020)

Key Components of a Biorefinery

maximizing the value of biomass resources by converting them into a wide range of products is one of the main aim of biorefinery. Here are the key components of a biorefinery:

Feedstock Handling and Preparation: Biomass feedstocks are subjected to certain physical pre-treatment like mechanical comminution, dewatering, and debarking among others to make them better suited for conversion processes (De Jong, 2014).

Conversion Processes: Although biorefineries are mainly based on biological systems, chemical, and thermochemical processes are used to convert biomass to desired products. Some of these procedures include; fermentation, enzymatic cracking, pyrolysis, gasification, and conversion through catalysis (Kumar & Verma, 2021)(Muh et al., 2021).

Product Separation and Purification: The formed product after conversion is then subjected to distillation or filtration and chromatography among others to produce pure biofuels, biochemicals, and other valuable products.

Waste Management: When evaluating biorefineries, the emphasis is made on reducing the amount of waste produced and on using as much of the available resources as possible. Byproducts and residues derived from conversion processes include the use of energy generation or subjected to other conversion processes to produce valuable products as shown in **Figure 1**. In figure 1, biomass being the central component in any modern biorefinery processing plant, could be processed to various byproducts (energy, fertilizer, biochemical, and food)

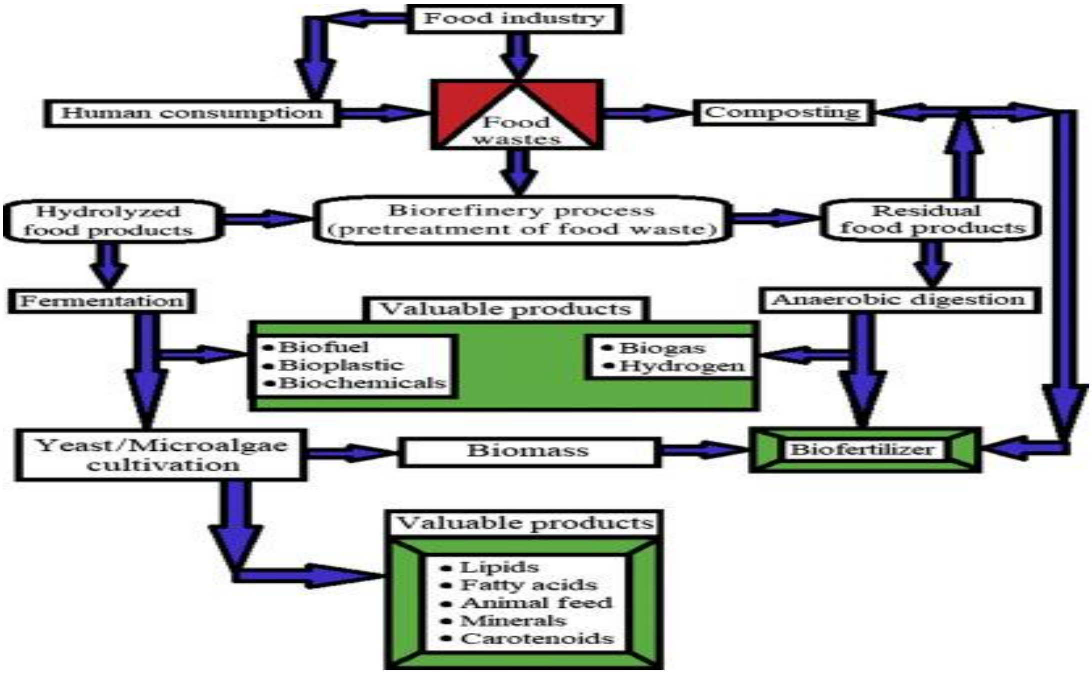

Figure 1: A schematic diagram of modern biorefinery

Source: ("Refining Biomass Residues for Sustainable Energy and Bioproducts," 2020)

Types of Biorefineries

Biorefineries can be categorized based on various criteria, including the type of biomass they utilize, the processes they employ, and the products they produce. Here are the main types of biorefineries:

First-Generation Biorefineries: These biorefineries are mostly concerned with the transformation of starch, sugars, and vegetable oils into bio-fuels which include ethanol and biodiesel. The main feedstock for these biorefineries are edible food crops which pose a debate on food versus energy crisis (Ladero et al., 2022). Consequently, this led to the emergence of second-generation biorefineries.

Second-Generation Biorefineries: these biorefineries use feedstocks that are not foods, these include agricultural residues, forestry residues, and energy crops for the development of biofuels and biochemicals.

Third-Generation Biorefineries: These biorefineries operate using algae, a type of biomass to generate biofuels, high-value chemicals, and other related commodities.

Integrated Biorefineries: Such amenities employ several conversion processes as a way of conducting a proper utilization of resources and production varieties. Many of them offer multiple biofuels, biochemicals, and bio-products from a variety of biomass feed streams.

BIOREFINING TECHNOLOGIES

Technologies used in biorefineries convert biomass into useful and valuable bio-products (Figure 2). Some key technologies used in biorefineries include:

Pretreatment:

For biomass to undergo conversion at a reasonable rate, preparatory processes are required to reduce the biomass structure to allow the subsequent conversion processes to take place. The major pre-treatments include mechanical grinding, chemical treatment (using acids or alkalis), steam explosive process, and enzymatic treatment (Silva et al., 2017).

Example:

Cellulose hydrolysis: $C_6H_{10}O_5 + H_2SO_4 \rightarrow C_6H_{12}O_6 + H_2O$

Delignification: $C_9H_{10}O_3 + NaOH \rightarrow C_9H_{10}O_3Na + H_2O$

Steam Explosion: $C_6H_{10}O_5 + H_2O \rightarrow C_6H_{12}O_6$

Hydrolysis:

The term hydrolysis refers to a breakdown of matter in biomass to simple carbohydrates which can be fermented to biofuels or biochemicals. Enzymatic hydrolysis is one of the key technologies in biorefineries in which enzymes are used to convert cellulose and hemicellulose into fermentable sugars (Vasić et al., 2021).

Enzymatic Hydrolysis: $C_6H_{10}O_5 + H_2O \xrightarrow{Enzymes} C_6H_{12}O_6$

Fermentation:

Fermentation processes, for example, involve the use of microorganisms, (fermenting organisms which include yeast or bacteria) to convert sugars obtained from biomass into fuels like ethanol, or chemicals like organic acids (Maicas, 2020). Fermentation is a key element for making various bio-based products in the biorefineries.

Glucose fermentation: $C_6H_{12}O_6 \xrightarrow{Yeast} 2C_2H_5OH + 2CO_2$

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Thermochemical Conversion:

Thermochemical conversion methods such as pyrolysis, gasification, and liquefaction expose biomass to high heat in the absence of air to obtain biofuel, synthesis gas, bio-oil, or biochar (Jha et al., 2022). Such transformation is applied in the production of renewable energy and other chemicals from mass-produced biomass feedstock. The chemical equations for the stated conversion methods are given below:

Pyrolysis:

Refers to the decomposition of organic materials into smaller molecules in the absence of oxygen under the influence of heat.

Biomass decomposition: $C_6H_{10}O_5 \xrightarrow{Heat} Char + Bio{-}oil + Gases$

Gasification:

Is the thermal decomposition of organic materials in the presence of limited amount of oxygen.

Biomass gasification: $C_6H_{10}O_5 + \frac{1}{2}O_2 \rightarrow 6CO + 5H_2$

Catalytic Conversion:

Catalytic conversion processes refer to processes where catalysts are used to promote the specific chemical reactions that produce biofuels and biochemicals. Besides, catalytic processes involved in the conversion of bio-oil upgrading, conversion of syngas to liquid and water to liquid fuels, and synthesis of high-value chemicals from bio-mass derived intermediate products.

Hydrogenation:

Hydrogenation is a chemical reaction in which hydrogen gas (H_2) is added to an unsaturated compound, such as an alkene or an alkyne, to produce a saturated compound.

Bio-oil upgrading: $Bio{-}oil + H_2 \xrightarrow{Catalyst} Hydrocarbons$

Separation and Purification:

The bio-based products need to be separated from reaction mixtures and pure components must be obtained and these technologies help in achieving this. Some other processes that involve distillation, chromatography, membrane separation, and solvent extraction to recover valuable compounds from biorefinery streams are also used (“Separation and Purification Technologies in Biorefineries,” 2013).

Distillation:

Ethanol purification: $Ethanol + Water \xrightarrow{Distillation} Pure\ Ethanol$

Bioreactor Systems: Biorefineries apply various forms of bioreactors for the process of fermentation, enzymatic hydrolysis, or microbial growth. Bioreactors give the most favorable conditions to encourage biological events and enhance production in a large scale.

Fermentation:

Microbial growth: $C_6H_{12}O_6 \xrightarrow{Microorganism} Biomass + Products$

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Product Recovery and Refining: Product recovery technologies are used to separate and recover bio-based products from biorefinery processes and to further upgrade the quality of the product if needed. For instance, biofuels, biochemicals, and biomaterials may be separated by means of filter and/or basement, crystallization, evaporation, and solvent extraction.

Crystallization:

Product purification: $Product\ solution \xrightarrow{Crystallization} Pure\ Product$

Process Integration and Optimization: Heat integration, mass balance optimization, and system modelling methods are used to enhance general performance, minimize energy requirements, and increment the profitability of biorefinery processes.

Figure 2 shows how different processing technologies could be used to achieve different product's selectivity. Thus, the rational and optimal use of these key technologies in biorefineries can provide a wide range of sustainable bio-based products from renewable biomass as part of the changing bio-based economy.

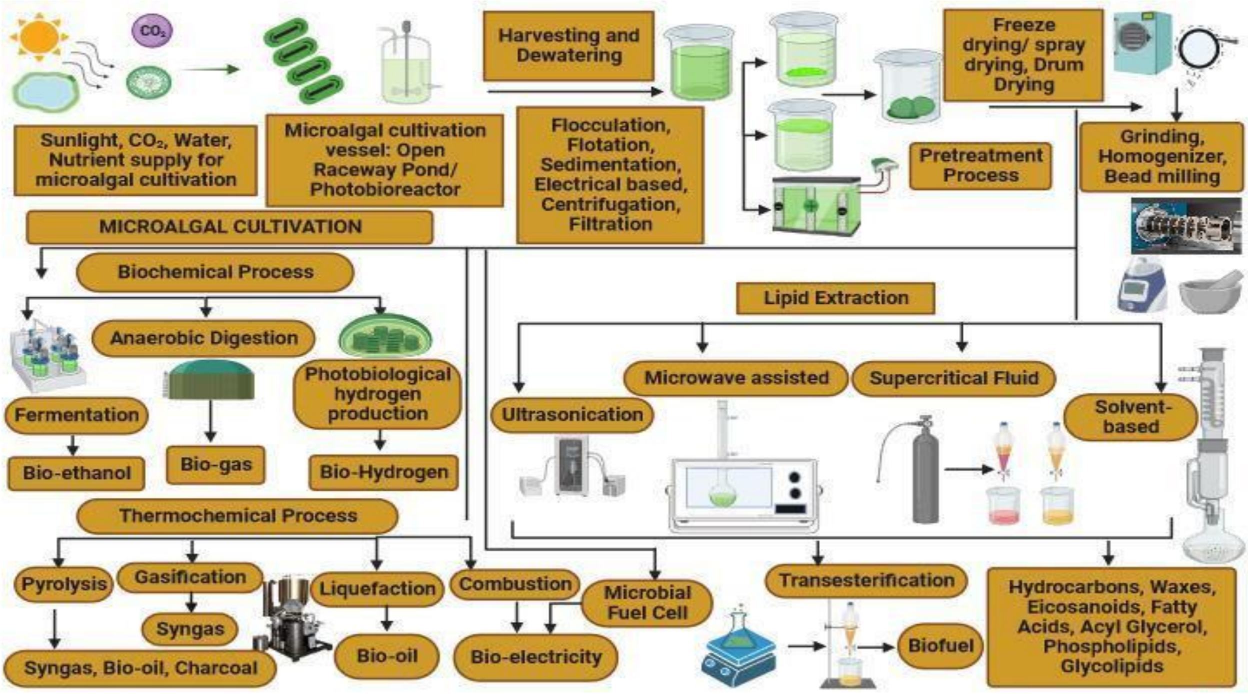

Figure 2: A schematic diagram of biorefinery technologies

Source: Chanana et al. (2023)

SOCIOECONOMIC IMPACTS OF BIOREFINERY IN THE GLOBAL SOUTH

The socioeconomic benefits of biorefineries in the global South can be significant and multifaceted (Conteratto et al., 2021)(Solarte-Toro & Alzate, 2023)(Rocha-Meneses et al., 2023). They include:

Job Creation:

Raw materials particularly are readily available in the rural regions, which is the common siting of biorefineries. They could thus result in the generation of employment opportunities in the rural areas. Under these circumstances, the quality of life of the local population may increase and the un employment rate may come down.

Effective revenue generation:

Due to this, biorefineries lead to the creation of a market for biomass feedstock and in turn an income stream for land owners or farmers. It can go a long way in being a pull away from poverty as well as an economic development for the region.

Value addition:

This could lead to enhancement of revenue for a local economy as well as have a factor on the utilization of the value chain for such biomass.

Technology transfer and innovation:

It is beneficiates in the sense that biorefineries are spread all over the region making technology transfer and the sharing of knowledge possible. This can support local innovation, skill, and capacity development aiming at lasting socio-economic development.

Energy Access:

Biorefineries thus have the potential to help in solving the power problem in rural areas through available local resources. This will assist in the eradication of energy poverty and improve the standard of living of those who are locked out from the mainstream supply of electricity.

Community Development:

Bio-refineries can enhance community transformation efforts within society by embracing people’s participation, social sensitivity, and sustainability. These could in turn foster improved social relations and community cohesiveness and resilience.

Environmental impacts of biorefineries in the Global South

Hence, the environmental effects of biorefineries are unique to their location and are determined by the sourcing of feedstock, application of technology, and the management of wastes that are produced (Fertahi et al.,2023). Some of the environmental impacts that should be considered are as follows:

Greenhouse Gas Emissions (GGE): Biorefineries can lower greenhouse gas emissions compared to the fossil fuel industries since they use renewable biomass to produce biofuels and biochemicals. Thus, the capacity for emissions reduction is relative and depends on the kind of feedstock used and the efficiency of production technology (Liu et al., 2023).

Land Use Change: Since the production of bioenergy for biorefineries involves land acquisition, there is likelihood of land use change with potential consequences on ecosystems, Biodiversity as well as Carbon sequestration (Núñez-Regueiro et al., 2020). The identification of sustainable feedstock from marginal or inactive territories helps to avoid the undesirable land use change effects (Mellor et al., 2020).

Water Use: Water is used in such biorefinery processes as pretreatment, fermentation, and cooling, amongst others. Thus, effective and efficient water practices are critically important to conserve water resources and avoid water pollution in the region (Li et al., 2023).

Waste Management: Biorefineries produce residues as by-products during feedstock conversion processes. These include lignin, ash, and wastewater. Recycling, reusing, and treating wastes generated in biorefineries are vital for the prevention of environmental pollution and the proper functioning of biorefineries (Chojnacka, 2023).

Air Quality: There are some emissions identified with some of the biorefinery processes like biomass combustion or fermentation emissions. If not checked, may result in adverse effects to the populace. The essential precautionary measures can be the employment of emission control technologies and monitoring of air quality in the potentially polluted atmosphere. (Ubando et al., 2020)

Resource Efficiency: Resource efficiency is a key objective in biorefineries, this means that the biorefineries should use less energy, generate as little waste, and use more of the biomass feed. Optimizing resources also offers the benefit of decreasing the accordant impacts on the environment and increasing the sustainability of biorefinery processes(Rehan et al., 2023).

Negative socioeconomic and environmental effects of biorefineries

Biorefineries' negative environmental and socio-economic effects in the global South could emanate from feedstock production, processing, waste disposal, and interaction with the communities. These are some of the negative effects that can be thought of; (Solarte-Toro et al., 2022) (Posada & Osseweijer, 2016) (Lopes & Łukasik, 2020).

Land Use Change: The production of bioenergy for biorefineries can be linked to changes in landscape, and in extreme cases may involve converting forests into bioenergy production areas, thereby displacing species and ecosystems. Many a time the natural ecosystem in the specific region of the world chosen for biomass production affects the environmental feedback in the long run (Solarte-Toro et al., 2022).

Water Consumption and Pollution: As for the water issue, water is used for process and cooling ie biorefinery operations, and the demand for water often exceeds the local water capacity and generates pollution if the water use system is imperfect. Direct discharge of wastewater and chemicals damages water sources and impacts aquatic life (Lopes & Łukasik, 2020).

Air Pollution: Certain biorefinery process methods like biomass combustion or fermentation can emit air pollutants emulsions like particulate matter, volatile organic compounds, and greenhouse gases. Air pollution poses several health and environmental effects to the society (Liu et al., 2023).

Resource Depletion: Excessive collection of biomasses for biorefineries has negative effects on the resources or ecosystem. The unbalanced sourcing practices have negative impacts such as soil degradation, erosion, and depletion of the ecosystem services (Lopes & Łukasik, 2020)..

Displacement of Communities: Large-scale development of biorefineries may remove the local populace or alter their way of living as land might be used to grow biomass. This can lead to social disorganization and destruction of the culture (Alam et al., 2021).

Labour Issues: There are scenarios where employment status at the different operations of the biorefinery may be low-skilled, informal workers, this often results in poor working conditions, low wages, and job insecurity. It somehow leads to social justifications and perpetration of social injustices and unfair treatment of others (Silva-Peñaherrera et al., 2022).

Health Risks: Inadequate waste management in biorefineries creates a health hazard to human beings doing the work and residents around the biorefineries. It is a direct infringement on workers' health as hazardous chemicals, emissions, and waste products, including dust, can cause respiratory ailments, dermatitis, and other diseases (Raphela et al., 2024).

Community Resistance: People in the local areas may object to the building of biorefineries since it is likely to cause; pollution, infringe on their rights to the land, and impact socially. Inadequate involvement and sensitisation of the people would result in opposition and conflict with the biorefinery projects (Solarte-Toro et al., 2022).

Economic Disparities: These centers or biorefineries may even worsen the existing poor economic distribution within the societies if several influential possess the positive aspects of others in the same society while several others acquire the negative aspects of biorefineries. The employment, income, and resource distribution disparity increases the socio-economic divides (Alibardi et al., 2020).

SUSTAINABLE FRAMEWORKS FOR THE ADVERSE SOCIOECONOMIC AND ENVIRONMENTAL EFFECTS OF BIOREFINERIES

Mitigating these adverse environmental and socio-economic effects entails the achievement of wide stakeholder consultations, sustainable utilisation practices and policies, and viable and workable regulation for biorefineries in the global South in order to attain sustainable development when considering their impacts on the environment and communities.

Thus, the biorefineries' adverse environmental and socio-economic effects in the global South necessitate more comprehensive measures entailing sustainability initiatives, stakeholder involvement, and legislation. These are some possible solutions:

Sustainable Sourcing: Extend best practice principles for biomass sourcing which includes utilizing biomass that does not compete with food production, refraining from the conversion of natural ecosystems to bio-energy production and ensuring the use of certified sustainable biomass resources (Solarte-Toro et al., 2022)..

Ecosystem Conservation: The preservation of the natural environment would require avoiding constant instances of deforestation, protection of endangered species and critical ecosystems, and support to landscape restoration efforts. It is therefore necessary that Bio energy / Biomass production should be made in a way that has minimal impacts on other land use values in; Nonetheless, the above can be offset through the employment of the land use planning strategies that considers both conservation and biomass production objectives (Solarte-Toro et al., 2022)..

Climate Mitigation: Strengthen the life cycle routes of bioenergy to achieve maximum potential in the avoidance of greenhouse gas emissions and carbon storage. Food production must not be hampered in the process of introducing bioenergy to the market through the consideration of the lifecycle emissions (Solarte-Toro et al., 2022)..

Community Engagement: Ensure that the course includes the appropriate approach to the biorefinery project and local communities. Participate them in decision-making processes, respond to their concerns and make sure that fair share of benefits has been received by the affected population (Solarte-Toro et al., 2022)..

Livelihood Support: Promote undertakings such as provision of skills development, and other income generating activities for the affected biorefinery communities. Support social integration, development, and opportunities programs for employment (Solarte-Toro et al., 2022)..

Labour Standards: Promotion of labour rights and occupational health and safety in biorefineries, so that the rights that employees have in the workplace may be safeguarded, fair wages paid and employment be secured for the employees. Ensure there is clearer promotion of training activities meant for employees and several promotions channel indicating where the workers could be promoted to (Silva-Peñaherrera et al., 2022).

Health and Safety Measures: Put in place adequate measures of health and safety which will safeguard the lives of the workers and the immediate community from the risks that are realized from biorefinery business. Ensure risk reviews and health risk assessments are done frequently to the identified risks (Raphela et al., 2024).

Conflict Resolution: Modern biorefineries should provide the policies to address the actual and potential conflicts, complaints and oppositions with the local communities that may appear from time to time.

Initiate meaningful dialogue and elucidate on issues that will facilitate the achievement of positive relations to manage social conflicts and achieve social harmony (Solarte-Toro et al., 2022).

LIMITATIONS OF THE RESEARCH

1. **Geographic Scope and Representation**: The research primarily focuses on the Global South, which encompasses a diverse range of countries with varying levels of development, infrastructure, and regulatory frameworks. The findings and conclusions may not be uniformly applicable across all regions, as local conditions, cultural contexts, and resources can significantly influence the feasibility and effectiveness of bio-refining technologies.
2. **Technology Variability**: Bio-refining technologies are rapidly evolving, with differences in efficiency, cost, and environmental impact. The chapter may not adequately capture the nuances of various technologies or represent the latest advancements, potentially leading to overgeneralizations about their applicability and effectiveness.
3. **Socio-economic Context**: The socio-economic impact analysis, while informative, may not fully account for the complexities and varying local dynamics within the Global South. Factors such as political instability, economic inequality, and social acceptance of bio-refining projects can significantly affect outcomes and were not explored in depth.
4. **Environmental Considerations**: Although the chapter claims environmental benefits associated with bio-refining, it may not sufficiently address potential negative environmental impacts, such as land-use changes, resource depletion, and biodiversity loss that can result from large-scale biomass extraction and processing.
5. **Policy Framework Impact**: The discussion on enabling policy frameworks may reflect an idealized view of how these policies can effectively promote bio-refinery technologies. The actual political landscape, bureaucratic resistance, and vested interests in the energy sector may pose significant barriers not fully explored in the research.

CONCLUSION

The integration of the tenets of biorefinery in the Global South provides the world with a unique chance to move forward to enhance the quality of life with regard to the impacting principles of development which are: energy, environment, and economy. Through the integration of advanced bio-refining technologies, these regions can transform their vast biomass potential into clean energy and valuable chemicals, thereby reducing reliance on conventional petroleum-based industries. The chapter underscores the importance of establishing robust policy frameworks that promote renewable energy initiatives and support the growth of bio-refineries, paving the way for improved energy independence and economic diversification. Additionally, the environmental benefits of these technologies highlight the potential for a more sustainable future

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