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Research Article

Assessment of Bioprocess Development-Based Modeling and Simulation in a Sustainable Environment

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Modeling and simulation help us gain a better knowledge of chemical systems and develop obstacles and improvement opportunities. In the initial stages of systems integration, the time and money constraints prevent more precise estimates, basic simulation software that provides a reasonable approximation of energy and material usage and procedure exhaust is typically useful. Every next era of technicians will confront a new set of difficulties, including developing new biochemical reactions with high sensitivity and selectivity for pharmaceutical industries and manufacturing lesser chemicals from biomass resources. This job will need the use of operational process systems integration development tools. The existing toolsneed improvement so that they could be used to examine operations against sustainability principles as well as profitability. Eventually, characteristic models for substances that aren't presently in collections will be necessary. In the field of integrated bioprocesses, there will undoubtedly be a plethora of new prospects for process systems engineering. The financial and environmental evaluations were based on a generic methodology for collecting first-estimate stock levels. The time it takes to do the evaluation may be cut in half, and a wider number of choices could be explored. A valuable commitment to sustainability bioprocess modeling and evaluation can be made by using a first-approximation numerical method as the basis for financial and environmental evaluations.

1. Introduction

Renewable resources such as grain production and accompanying leftovers, wood residues, coastal biomass combustion, industrial engineering creeks, and food system side creeks are all used in the manufacturing of bio-based chemicals and polymers. To evaluate the fermentation process synthesis of bio-based chemicals and polymers within a biopolymer matrix, measure feedstock supply as well as the spatial location of important IFSS feedstocks [1]. Traditional fermentation technologies are now widely acknowledged to be less expensive than hydrocarbon processes. As a result, biomass processing should be optimized in comparison to applicable comparisons (e.g., comparable hydrocarbon byproducts), taking into account the assessment of the innovative, environmental, and social aspects. While the original upstream to downstream relied solely on fungus, germs, and microbes, the inclusion of enzymes and eukaryotic cells eventually expanded industrial output. Other biocatalysts, such as the cells of the insect and plant, as well as transgenic plants and animals, have been introduced to the technology platform, but have yet to be deployed in manufacturing. Simultaneously, the brewing process and downstream methods were improved, and the technology and quality of bioprocess design increased dramatically.

These emphasize the use of abundant renewable inputs in conjunction with sustainable electric power, particularly solar or wind, as an electrostatic field [2]. It is expected that, especially in cities, such electricity will become the main kind of energy, allowing geographically spread biomass should be used more extensively in a descending strategy to provide food, feed, and the essential carbon dioxide concentration for pharmaceuticals while using less energy. The indirect or direct connection of the different sources of carbon and energy is possible. Researchers need to create life-changing, life cycle, systematic problem-solving architectures, tools, and strategies to endorse strategy and regulatory preparation and also company decision - making process in efforts to progress the inter-/cross-/trans-disciplinary conceptions of environmental protection, ecological/evolutionary economics, physical and biological economic, sustainability engineering and science in having to confront advancement issues. Different sustainability-related research has emphasized the importance of establishing these integrated tools and methodologies to support policies, legislation, and practices for environmental sustainability at both the regional and international levels [3]. The bioindustries have grown to a critical level, and they rely on a comprehensive understanding of genomic, proteomic, informatics, genetic transformation, and molecular breeding [4]. Bioprocesses are used in a variety of industries nowadays, as shown in Table 1shows Process Industry vs Microorganisms.

Biorefinery technology should be used to make valuation bio-based goods from different renewable energy sources, including agricultural wastes, forest resources, algal feedstock, and IFSS. Cellulose and lignin biomass is defined as the first two residues. Yellow biomass, which refers to wastes resulting from any growing crops, is one of the biomass feedstocks that is primarily planted for organic material, methane, or other biofuels generation (e.g., corn stover, wheat straw) [5]. Crop residue-related factors are closely linked to the development of industrial units in the best location. Biofuels have a good outlook since they can reduce fossil energy reliance while also reducing environmental consequences and chemical pollutants resulting from reduced utilization of such supplies. There are a few critical characteristics of biofuels that are strongly linked to the selection of biomass resources and the development of biorefinery processes and technologies.

Change is an inherent aspect of natural systems, according to these definitions. Sustainability must be an element of such transition, to induce reasonable human progress rather than protection. The three major aspects of sustainable development, according to the WCED (1987), are the so-called "triple bottom line." These pillars serve as a framework for focusing efforts toward achieving the goal of "responsible human development." Economic feasibility, environmental management systems, and community involvement are the three pillars indicated in Figure 1 Major Aspects of Sustainability Development.

The three aspects of sustainability have frequently been depicted as a mutually beneficial relationship. These parameters can be more precisely described in the context of sustainable process development and design (a central issue of the thesis) [6]. The application of scientific methods to optimize the use of resources and energy localized to the manufacturing process is at the heart of strong sustainability concerns.

As a result, selecting operating pathways for a biorefinery layout becomes a critical issue that must take into account process flow sustainability. As a result, there is genuine interest in developing biorefinery syntheses and enhancement simulations to assist decision-makers in the implementation of construction projects. The primary benefit of using biofuels is that they are more environmentally friendly than traditional fuels (gasoline) throughout their complete lifecycle (resource creation, resource exploitation, product manufacture, and product consumption stages) [7]. The pollutants from farming activities and planting are generally removed or decreased in cellulosic biofuels, especially those made from agro-industrial residues, resulting in a lower ecological footprint than the first decade of biofuels.

Membrane-based, gas-liquid equilibrium and liquid-liquid state of balance are some of the separating concepts used to help with product separation. This research looked into the impact on the environment of biodiesel production, a more appealing gasoline alternative than bioethanol. The need for a pre-concentrate phase before the process of distillation is more crucial for the butanol-water mixture than with the ethanol-water mixture, even though butanol and water form an azeotrope mixture at low butanol concentrations, and the eventual results azeotrope combination has much different boiling points than the ethanol-water azeotrope mixture [8]. Over the next few decades, the use of bioprocesses in various sectors will skyrocket. Bioprocesses could also be used in industries in which they are not currently utilized or where mainly lab-scale procedures are being explored, such as the development of novel substances with new qualities that mimic natural materials. The confluence of biotech, nanomaterials, and information and technology is predicted to result in a significant rate of advancement and expansion. The role of information technology has indeed improved random drug testing and manufacturing, as well as our knowledge of biological systems. It could also lead to bio-chips replacing silicon-based processors in computers.

Sustainable chemical compound manufacturing necessitates a renewable source of carbon, as well as a renewable source of energy if the carbon dioxide is insufficiently energetic. As seen in Table 1, there are several phases of biotechnological processes. The benefits and drawbacks of the early generations are well-known.

Table 1: Process Industry vs Microorganisms.

Organization	Complexity of downstream	Scale	Byproducts	Biocatalyst	Market share biotech
Elementary chemical	Super low	Large	Small organic molecules	Enzymes/micro organic	Super low
Fine chemical	Average	Average	Small organic molecules	Enzymes/micro organic	Low
Cleansing agent	Low	Large	Enzymes	Micro organic	Average
Medical care/ cosmetics	Average - high	Small – Average	Small molecules and proteins	Mammalian cells/enzymes/micro organic	Average
Conventional biopharma	Average - high	Average	Small organic molecules	Mammalian cells/micro organic	Low- average
Food and feeds	Average	Super large	Proteins and others	Enzymes/micro organic	Average
Mining metal	Low	Super large	Metal and metal compounds	Micro organic	Super low
Treatment of waste	Super large	Low	Purified water air and soil	Micro organic	High

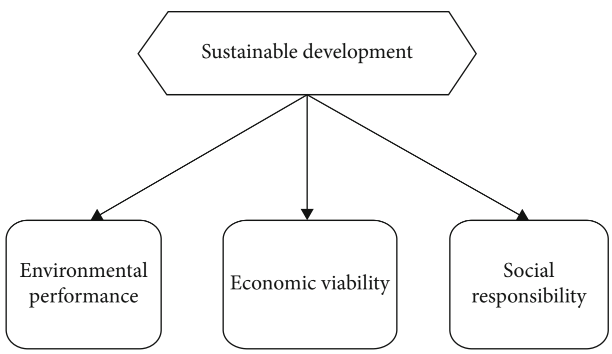

Figure 1: Major Aspects of Sustainability Development.

2. Related Work

The researcher proposed a method for the sustainable production of bio-based chemicals and polymers through integrated biomass refining and bioprocessing based on the circular bioeconomy context. The establishment of feasible bio-refinery models using crude renewable energy sources for the production of varied products is critical for the long-term manufacture of bio-based chemicals and monomers. The accessibility of fractionation co-products and fermentation products that could be obtained from big manufacturing and food distribution network side streams in EU countries is presented in this serious assessment. Fermentable sugars have the potential to be used to make bio-based pharmaceuticals and polymers. Following circular bioenergy principles, the application of bio-refinery ideas in business should be evaluated based on operational success and effectiveness, which includes a techno-economic, environmental, and social impact analysis. Edge possibilities and incorporating sustainability metrics have been provided. A case study of the innovative evaluation of bio-based carboxylic acid secretion from the lignocellulosic biomass waste was provided, with an emphasis on the process efficiency and substrate demand [9].

Synthesis and Sustainability evaluation of a lignocellulosic defines the multifidous biorefinery with the consideration of various technical performance and indicators. This study presents a novel research method for a self-sustaining design process predicated on this motivation, which includes synthesis of a multifidous optimal biorefinery while simultaneously optimizing environmental and economic objectives, while further sustainability assessment that uses the sustainable development balanced return on the capital metric. Researchers performed environmental, safety, economic, and power assessments to examine the system, which is a study conducted for north Colombia after the model synthesized the best biorefinery. The mathematical model provided the data required to create the system assessment process using the Aspen Plus software (expanded material and momentum balances, properties estimations, and downstream modeling). The environmental and economic evaluations revealed that the assumptions used to solve optimization problems were sufficient, resulting in positive financial and environmental consequences [10].

Impact on the environment evaluation is important of biodiesel synthesis since it ensures that emissions are kept to a minimum. The preprocessing and downstream manufacturing phases of a typical cellulosic ethanol manufacturing process were observed to use a lot of chemical products and energy, resulting in a lot of emissions. The biochemical, water, and energy, and wind of cellulosic bioethanol production utilizing low water anhydrous ammonia (LMAA) preparation was projected to be minimal, particularly when the method was paired with more effective downstream processing methods. The life-cycle assessment of various pretreatment and product proposed by the researcher deals with the separation technology for the Butanol Bioprocessing. When contrasted to other predicted pretreatment methods, the analysis indicates that LMAA preparation had commercial viability due to its low energy consumption. LMAA preparation resulted in strong security measures that reduced the chance of anhydrous ammonia leaking into the air [11].

The grand research challenges for sustainable industrial biotechnology proposed by the author define the different issues in the biotechnology process. Unique, enhanced commodities and new, advanced production technologies will be the reference for future production. Recent biotechnological and academic breakthroughs, like as CRISPR-Cas and omics technologies, are paving the way for exciting new biotechnology research, production, and implementation of new sustainable goods. Deeper biologic comprehension and robust in silico biochemical markers will be enabled by mathematically rigorous explanations of microbes and communities. Biological design, which combines model-based architecture and biomedical engineering, will speed up the development of resilient and high-performing microbes. Commercial biotechnology is projected to become strongly incorporated into self-sustaining eras of technology systems based on these creatures and aims toward zero-concepts in terms of greenhouse gas emissions and surplus materials in bioprocess engineering [12].

The author done research on the advancing integrated system modeling explaining the framework for the cycle sustainability assessment. Due to the increasingly multiple environmental systems concerns, the need for integrated conditions stipulated for life cycle assessment has been widely explored and is urgent. These issues affect the environment and human well-being, posing a danger to countries' and enterprises' economic success. The integrated assessment considers several concerns, covers regional and temporal scales, looks forward and backward, and includes input from multiple stakeholders. The goal of this research is to create an integrated technique by combining the capabilities of distinct industrial environmental scientists' and physicochemical economists' methods.

3. Materials and Method

Like other biochemical reactions, bioprocesses require a variety of material and energy inputs, as well as specialized unit activities and supplementary requirements. Bioprocesses are also often divided into three different categories: upstream operations, bioreaction, and downstream operations. All three components, as well as their accompanying operations, must be examined and incorporated into the flowsheet model. It's critical to specify the model's limits and planned use precisely so that all of the components designed to accomplish the model's goals are included [4]. The simulation approach employed is determined by the simulation's goal. Gathering the appropriate process data is the first step in creating a flowsheet model. This is incorporated into a structural model that is tailored to the system for assessment.

3.1. Sustainability in Bioprocess Development. The large assortment of goods and services created by the bioprocessing industry has the potential to generate substantial value. Due to the promoted advantages of functional ingredients, regenerative feedstocks, decrease pollution, and advantageous operational requirements, bioprocess architectures are rapidly being used over conventional chemical production technologies. Furthermore, the economic benefits derived from procedures that use sustainable feedstocks, such as lower emissions costs and higher consumption of natural ingredients, appear to be well justified [13].

Changes to process units and retrofit with new technology can help biomanufacturing plants enhance energy consumption, improve net consumption of water, and minimize waste output in an attempt to enhance the performance of the process. By minimizing greenhouse emissions and natural capital use, this method to better process innovation can assure a more ecologically friendly process. It is, nevertheless, just as critical, if not, even more, to develop more economical and environmentally efficient procedures initially in the process development phase [13]. Changes to process units and retrofit with new technology can help biomanufacturing plants enhance energy consumption, improve net consumption of water, and minimize waste output in an attempt to enhance the performance of the process. By minimizing greenhouse emissions and natural capital use, this method to better process innovation can assure a more ecologically friendly process. It is, nevertheless, just as critical, if not, even more, to develop more economical and environmentally efficient procedures initially in the process development phase.

3.1.1. Process Development Assessment and Designing. This information can be improved by modeling the design process and performing a comprehensive assessment. To realize viable manufacturing processes, a continuous examination is needed [14]. Decisions must be based on accurate assessments of an application's costs and potentials, as well as the identification of 'hot spots in the production timetable. This is known as integrated planning, and it should involve environmental and economic evaluations.

The above Figure 2 Decision in the Process Development is defined based on the basic parameter. The more sophisticated the design of the system, the more the ultimate process of production, including its pricing structure and environmental consequences, is already known. The expense of redesigning to address a previously unnoticed issue climbs as the development stage progresses. End-of-pipe technology, which incurs added expenses, is frequently the only solution to environmental issues at a different stage of development [15].

Gaps in the data and uncertainties in the development phase result in an imperfect image of the predicted production-scale process. Process modeling can bridge this gap as well as provide a solid foundation for evaluation. The following Figure 3 Process development of Bioprocess shows the iterative aspect of designing and developing of bioprocess.

Further data is acquired from trademarks, publications, and other alternative entities, and the models should indeed be produced in close coordination with the design process. The simulation findings are used to assess the process and steer R&D resources toward the most promising avenues and pressing issues. As a result, it's critical to consider the entire process rather than just a single stage, such as the fermentation step, which is separated from the rest of the

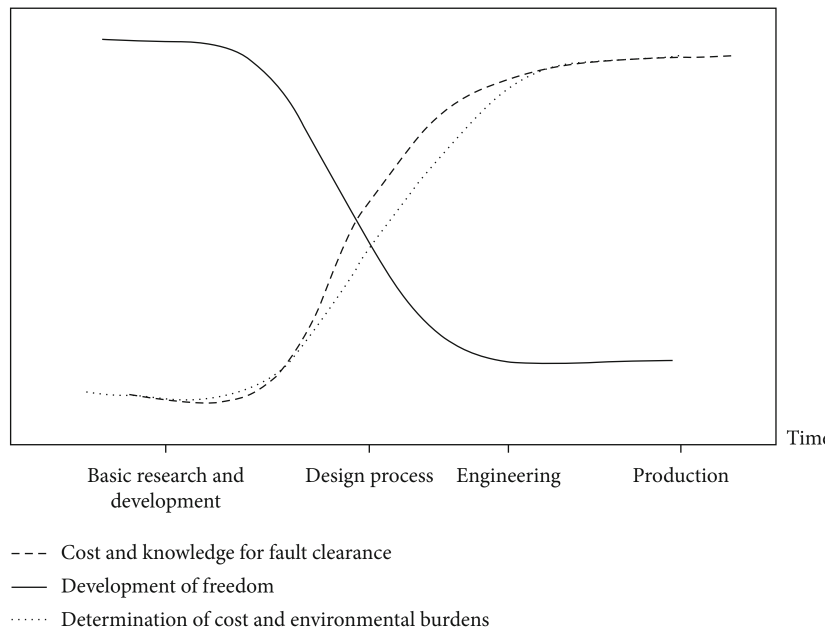

Figure 2: Decision in the Process Development.

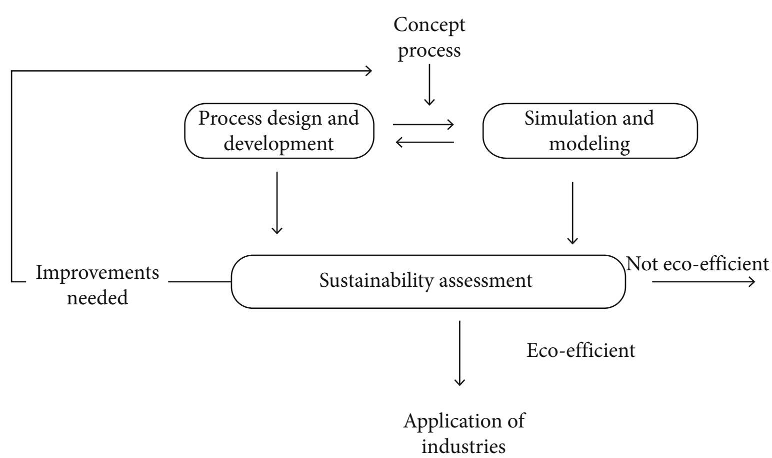

Figure 3: Process development of Bioprocess.

process. The main goal is to create the most competitive and long-lasting process possible [8]. The modeling and evaluation procedure is done iteratively and necessitates a multidisciplinary approach. Important obstacles that may obstruct a successful transfer to an industrial use can be detected sooner using this approach, eliminating R&D waste. Consequently, the predictions that are generated and the assessments that are based on such models have some inherent uncertainty. This inconsistency must be taken into account and quantified.

3.2. Flowsheet Model. For bioprocesses, a basic flowsheet model was created. For Life Cycle Analysis of bioprocesses, the worksheet model was created to generate first-estimate energy and material equilibrium inventory data. The researcher began developing the model on the assumption that these data are often difficult to get or not accessible at all during the initial phases of process development. The model's energy and material equilibrium data can be used to create inventory items for Life Cycle Analysis of particular bioprocesses. The flowsheet was created to address three key requirements for a general initial phase simulation tool:

The flowsheet should act as a first-estimate bioprocess simulation tool

The tool should provide all relevant data for a comprehensive Life Cycle Assessment (LCA).

The flowsheet should require minimum input data to yield a first stage estimate which can be

refined on the availability of more comprehensive data

Produce first-estimate energy and material balance data for specified bioprocess models using the generic flowsheet model. Microsoft Excel is used to create the flowsheet (MS-Office 2008). Model characteristics and calculation processes are mostly based on basic principles and relevant published

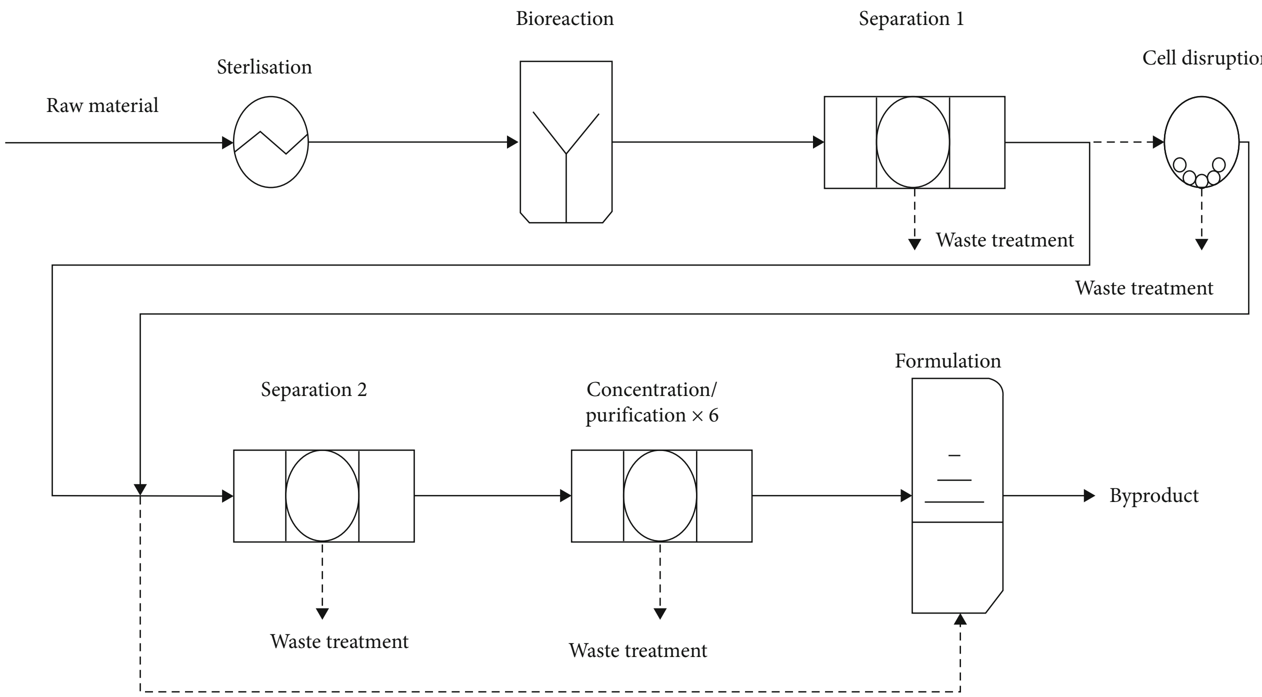

Figure 4: General Process Flow Diagram.

Table 2: Input requirement and simulation.

Procedure	Input of user	Output simulation
Complete process	(i) Selection of batch or continuous operations (ii) Selection of liquid or solid and intra or extracellular products (iii) Selection based on the growth of anaerobic or aerobic biomass (iv) User-defined product quantity	(i) Energy and material requirement (ii) Categorizing the waste material (iii) Recovery and product purity
Sterilization	(i) Media sterilization	(i) Energy and material requirement
Bioreaction	(i) Growth rates, the concentration of biomass, and yield coefficients are required (ii) Maintenance calculation is included for selection	(i) Microbial growth prediction (ii) Requirements of antifoam and agitation
Waste treatment	(i) Waste treatment selection	(i) Chemical oxygen demand
Cooling	(i) Relevant cooling is included	(i) Energy and material requirement
Downstream	(i) From the built-in model, the downstream is specified	(i) Energy and material requirement

information [16]. A typical large-scale bioprocess flowsheet is defined by six successive processes in the model. As the user describes the process, a modified flow process diagram, displayed in Figure 4 General Process Flow diagram shows the sequential selection of potential process units in each stage.

Batch or continuous microbial growth with intracellular or extracellular product production is possible with this technology. The process's energy and material consumption are controlled by the number of products manufactured. Liquid–solid extraction, cell destruction, as well as further filtration precede sterilization, inoculation, microbial growth, and manufacturing of products. Selecting from several unit operations seen in bioprocesses is how downstream treatment is defined. Six concentration or filtration processes are proceeded by a last composition step in the downstream unit. In downstream operations, the recycling of process

Table 3: Material Balance form starch.

Components	Generic flowsheet	
	In	Out
Ammonium nitrate	23.5	—
Biomass	0.356	—
Carbon dioxide	—	157
Citric acid	—	354
COD	—	0.693
Fat	—	1000
Glucose	—	30.5
Hydrogen chloride	0.713	299
Nitrogen	19581	19581
Oxygen	5951	5485
Starch	1201	—
Water	13235	13235

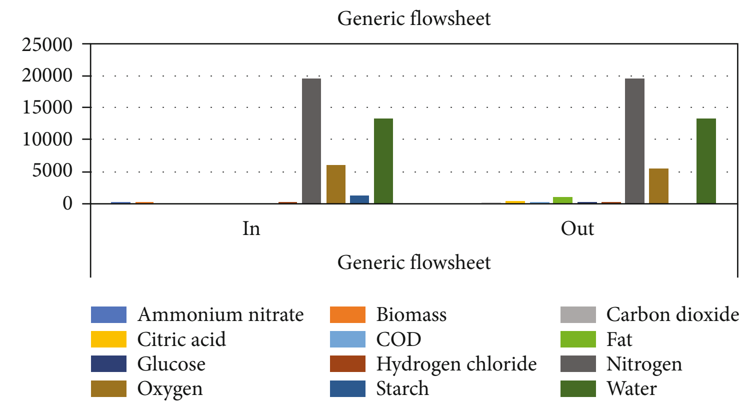

Figure 5: Generic Flowsheet Comparison.

steps is not factored into the equation [14]. Even though the general flowsheet includes attribute values for input variables based on research and production practices, certain essential default values should be checked against procedure research or facility data to guarantee minimal departure from the overall procedure. The parameter estimation for manufacturing found crucial factors. Modifications in these crucial variables have a significant impact on the energy and material balance outcomes of the typical flowsheet. The changes have an impact on the Life Cycle Assessment scores, thus careful evaluation of these factors is required to measure the reliability and validity are as accurate as a first-estimate expense analysis. The following Table 2 displays Input requirement and simulation output based on Flowsheet depicts these six processes as well as the most crucial elements of each.

Selecting from a variety of unit operations seen in bioprocesses is how downstream processing is defined. Six concentration or purification steps are proceeded by a last formulation step in the downstream unit. In downstream operations, the recycling of process steps is not taken into account. Even though process variables for individual component activities can be defined, default settings for chosen units that are typically found in bioprocesses are supplied [17]. Yield ratios, material mixtures, and densities, working pressure and temperature, and enhancing the capabilities are all standard values. The researcher provides a full explanation of the unit operational theory, computation techniques, and default values. The process needs minimum inputs to get precise predictions for material and energy balance data because it was designed for evaluation in the early phases of process development.

Table 4: Energy and Utility Requirement.

Input utility	Generic flowsheet
Electricity	10895
Adsorption	1.84
Aeration	5375
Agitation	2898
Crystallization	39.8
Drying	228
Filtration	565
Ion exchange	1.84
Steam	141005
Bioreactor	1885
Crystallization	11065
Drying	785
Sterilization	380
Cooling water	2235
Aeration	1195
Bioreactor	—
Condenser	995
Sterilization	50
Chilled water	207
Bioreactor	198
Crystallization	8.99

3.3. System Engineering Process and Its Role

3.3.1. Process Option Evaluation. Existing infrastructure, input costs, feedstock availability, and the effectiveness of the necessary (bio)catalyst and (bio)process technology are all economic factors for deployment. Simultaneously, there are environmental and, in a broader sense, sustainability considerations that influence the choice of various process options. The evaluation of the greenhouse effect and the design to reduce or prevent this impact are two examples of current uses of process system analysis. For example, they recently advocated using process systems engineering methods like conservation of mass, thermodynamics, and process work balances to reduce energy use and greenhouse gas emissions [11]. This is an instance of how simulation design and thermodynamics can be used to create measurements and objectives for key elements or consequences. This is also an illustration of current techniques that tend to concentrate on a single effect and its following measure.

Process systems engineering plays a key role in enabling quantitative analyses of such processes, not just from a process standpoint but also from a larger sustainability point of view. Detection and quantification are important because it allows for thorough comparisons and judgments, which boosts decision-making confidence. Rapid computational

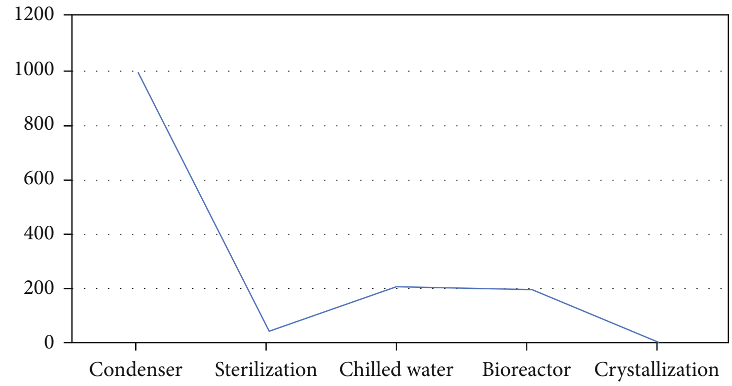

Figure 6: Energy and Utility.

models are also a benefit of process systems engineering. Solutions can be swiftly explored using such simulators. This is critical in allowing tools to be used beginning of the project and product creation. Finally, the response to the challenge posed here will be influenced by regional characteristics in a specific example.

3.3.2. Chemical Platform Evaluation. Aside from biomass, there are several potential options for fuel supply and availability. It's less apparent where the chemicals for the next generation will come from in a world where oil is scarce (or very expensive). There is presently an infrastructure in place that is based on the utilization of the seven well-known platform chemicals. In the medium run, we could investigate repurposing existing infrastructure to make the seven compounds from alternative energy sources. In the long run, new procedures due to a different set of raw materials will be required. A few groups will be dependent on fructose. In a biorefinery, it will be important to create a framework that can handle a variety of feedstocks, methods, and outputs. This poses a significant design and optimization, as well as system integration, problem.

(1) Process Integration. With a few exclusions, water is the principal mediator for most bioprocesses. As a result, the downstream process is typically challenging, which is exacerbated by the requirement to perform breakups at warmer temps. Because of the dilute nature of rivers, the preponderance of the environment and expense, safety, and health implications are typically found in the downstream process [18]. The necessity for energy-intensive segregation has traditionally been driven by the dilute character of the streams. For bigger density estimation, such as petroleum products, evaporation of water becomes a must to cut costs and prevent carrying large quantities of water. In other circumstances, the output may be included in a biorefinery system, however, water will have to be eliminated at some stage.

As a result, incorporating water consumption and recovery via recycling into the design of industrialized bioprocess plants is critical. Furthermore, bioprocesses must be built using processes synthesis and system integration methods to prevent having a procedure that is efficient in one section but wasteful in another. Conventional material and energy integration methods, such as squeeze innovation, will play a key role. In many respects, the problem of water incorporation in a biorefinery is similar to the problem of thermal storage in a traditional refinery.

Table 5: Result of Impact.

Impact	Generic flowsheet	Difference
Abiotic depletion	0.45	0.22%
Ozone depletion	5.81E-08	0.17%
Global warming	4.5	1.5%
Aquatic economy	0.47	-3.3%
Marine economy	1805	0.00%
Human economy	1.85	-0.50%
Acidification	0.025	-1.1%
Eutrophication	0.0099	-4.8%

(2) Design of Biorefinery. Exploitation to produce a variety of sugars (for (bio)catalysis or ferment) as well as oil-based material. In each scenario, the present focus of the biorefinery study is to find that all fractions of a given feedstock are fully used in a given environment. Similarly, the development of downstream goods is currently being investigated. Glycerol, for illustration, can be utilized as a foundation chemical because it is a byproduct of biodiesel manufacturing [19]. Another fascinating case in point is the manufacturing of bioethanol. Although biofuel is widely used as a fuel, there is a solid economic incentive to produce a wide range of different products from it or to use it as a foundation chemical. There seems to be little question that the expanding spectrum of technologies and opportunities available as a result of enzyme- or fermentation-based catalysis will create complicated integration challenges that may necessitate the development of new tools.

(3) Design of Biocatalyst. Bioprocesses are distinguished by their usage of biocatalysts, which come in a variety of forms, as previously mentioned, and can be modified. The alternatives for switching amino acids via protein engineering exist at the most basic level as a protein (isolated enzyme). New enzymes that have been changed may also have better

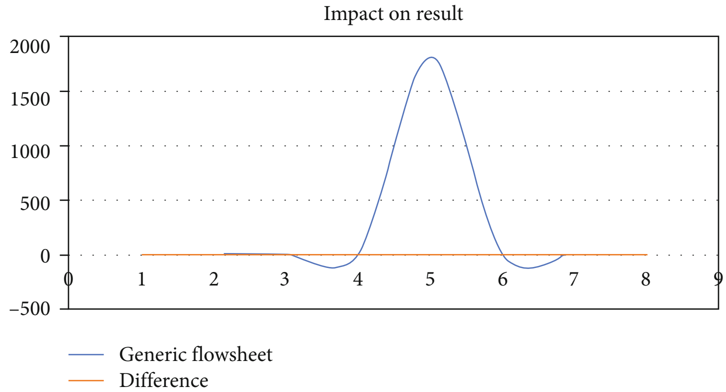

Figure 7: Impact on Result.

selectivity or responsiveness (activity) on a particular (non-natural) target or reaction, as well as new sensitivity to reactors conditions like temperature or pH value [20]. Through a mix of genetic manipulation and de-novo route design, some progress has been made toward the construction of systems in which proteins from many sources are cloned into a host machine to create a novel route. Individuals working in process system design must teach biological designers about what is needed in a given scenario and set appropriate targets in all of these domains.

4. Result and Analysis

Differences in simulation outcomes might also be ascribed to the simulated frameworks' computation methodologies. The bioreaction estimates in the generic flowsheet model were predicated on output to biomass proportion and yield constants, whereas the bioreaction outputs were determined using explicit chemical processes and limiting nutrient content. Because of the inherent differences in the models, the computed values are likely to vary. Variations in computation results can also be caused by default values for non-critical input parameters. The following Table 3 Material Balance form starch shows the in and out model of the generic flowsheet.

The following Figure 5 Generic Flowsheet Comparison is represented. For a variety of material outputs and inputs, the numerical solution outcomes for the various models differ. The presumption that surplus nutrients were provided to the system resulted in higher waste flowrates of glucose, ammonium nitrate, and potassium phosphate in the generic model. The increased yield due to improved process recovery in downstream processing is linked to the generic simulation's lower starch demand.

Table 4 summarizes the energy and utility requirements, which comprise power, steam, cooling water, and chilled water. In terms of energy and utility requirements, the process models contrasted rather well, as shown in Figure 6 Energy and Utility. The bioreactor's air compression and mechanical movement consumed the majority of the electricity in both modeling techniques. The compressor's electrical requirement was dictated by the aeration rate and period of the bioreaction.

Sterilization, medium heating, evaporation in the crystallization unit, and final product drying all required steam. For turbine cooling and isothermal bioreactor operation, cooling water was used. The temperature of the bioreactor was controlled with chilled water, which was also utilized to cool the solution during crystalline structure.

The outcomes of the above analysis suggest that LCA is most useful for method development in the initial stages of process development when decision-making is often based on process designs with drastically different sales data. LCA is likely to reveal significant disparities in effect classifications for processes involving various feedstocks and processing pathways and it is mentioned in the following Table 5 Result of Impact.

The above Figure 7 Impact on Result demonstrates that the generic flowsheet model could be used to create inventory items of adequate quality for use in life cycle impact assessments of large-scale bioprocesses for original decision comparability.

5. Conclusion

New bioprocess chemical and fuel generation technologies are an intriguing endeavor that will keep many process engineers busy in the future. Process systems engineers will play a vital role in this growing industry, thanks to the benefits of quantified decision-making tools and quick modeling and intended to cause and environmental principles. In the future, appropriate models will guide innovations at the infrastructure, process, and catalyst levels (assessment of various solutions and system integration) (evaluation of alternatives for protein and metabolic engineering). More rigorous and consistent life cycle environmental inventory datasets of bio-derived components and better modeling and awareness of social and economic dimensions of sustainability and their connections will be required to assess the sustainability of bioprocesses regularly. Finally, to fully exploit the goals of sustainable development biotechnological processes, increased dialogue among biochemical engineers, biologists, and other professionals with relevant areas of competence will be required.

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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References

[1] A. Halog and Y. Manik, "Advancing integrated systems modelling framework for life cycle sustainability assessment," *Sustainability*, vol. 3, no. 2, pp. 469–499, 2011.

[2] J. Du, B. Kuang, and Y. Yang, "A Data-Driven Framework for Smart Urban Domestic Wastewater: A Sustainability Perspective," *Advances in Civil Engineering*, vol. 2019, 15 pages, 2019.

[3] C. Jiménez-González and J. M. Woodley, "Bioprocesses: Modeling needs for process evaluation and sustainability assessment," *Computers & Chemical Engineering*, vol. 34, no. 7, pp. 1009–1017, 2010.

[4] Z. Usmani, M. Sharma, A. K. Awasthi et al., "Bioprocessing of waste biomass for sustainable product development and minimizing environmental impact," *Bioresource Technology*, vol. 322, article 124548, 2021.

[5] K. Harding, *A Generic Approach to Environmental Assessment of Microbial Bioprocesses through Life Cycle Assessment (LCA)*, 2008.

[6] C. L. Gargalo, P. Cheali, J. A. Posada, A. Carvalho, K. V. Gernaey, and G. Sin, "Assessing the environmental sustainability of early stage design for bioprocesses under uncertainties: An analysis of glycerol bioconversion," *Journal of Cleaner Production*, vol. 139, pp. 1245–1260, 2016.

[7] N. S. Vasile, A. Cordara, G. Usai, and A. Re, "Computational analysis of dynamic light exposure of unicellular algal cells in a flat-panel photobioreactor to support light-induced CO2 bioprocess development,," *Frontiers in Microbiology*, vol. 12,, 2021.

[8] E. Heinzle, A. P. Biwer, and C. L. Cooney, *Development of Sustainable Bioprocesses: Modeling and Assessment*, John Wiley & Sons, 2006.

[9] S. M. Ioannidou, C. Pateraki, D. Ladakis et al., "Sustainable production of bio-based chemicals and polymers via integrated biomass refining and bioprocessing in a circular bioeconomy context," *Bioresource Technology*, vol. 307, article 123093, 2020.

[10] S. I. Meramo-Hurtado, E. Sanchez-Tuiran, J. M. Ponce-Ortega, M. M. El-Halwagi, and K. A. Ojeda-Delgado, "Synthesis and sustainability evaluation of a lignocellulosic multifeedstock biorefinery considering technical performance indicators," *ACS Omega*, vol. 5, no. 16, pp. 9259–9275, 2020.

[11] N. Mahmud and K. A. Rosentrater, "Life-Cycle assessment (LCA) of different pretreatment and product separation Technologies for Butanol Bioprocessing from oil palm frond," *Energies*, vol. 13, no. 1, p. 155, 2020.

[12] A. J. J. Straathof, S. A. Wahl, K. R. Benjamin, R. Takors, N. Wierckx, and H. J. Noorman, "Grand Research Challenges for Sustainable Industrial Biotechnology," *Trends in Biotechnology*, vol. 37, no. 10, pp. 1042–1050, 2019.

[13] P. Tilak and M. M. El-Halwagi, "Process integration of Calcium Looping with industrial plants for monetizing CO2 into value-added products," *Carbon Resources Conversion*, vol. 1, no. 2, pp. 191–199, 2018.

[14] S. Cortina, P. Valoggia, B. Barafort, and A. Renault, "Designing a data protection process assessment model based on the gdpr," *European Conference on Software Process Improvement*, vol. 1060, pp. 136–148, 2019.

[15] D. Petrides, C. L. Cooney, L. B. Evans, R. P. Field, and M. Snoswell, "Bioprocess simulation: An integrated approach to process development," *Computers & Chemical Engineering*, vol. 13, no. 4–5, pp. 553–561, 1989.

[16] A. Bond, A. Morrison-Saunders, and G. Stoeglehner, *Designing an Effective Sustainability Assessment Process*, Routledge, Taylor & Francis Group, 2013.

[17] P. Bergström, "Designing for the unknown: didactical design for process-based assessment in technology-rich learning environments," *PhD Thesis, Umeå Universitet*, vol. 2013, 2013.

[18] C. Mao, N. Zhai, J. Yang et al., "Environmental Kuznets Curve Analysis of the Economic Development and Nonpoint Source Pollution in the Ningxia Yellow River Irrigation Districts in China," *BioMed Research International*, vol. 2013, 7 pages, 2013.

[19] K. H. Zhuang and M. J. Herrgård, "Multi-scale exploration of the technical, economic, and environmental dimensions of bio-based chemical production," *Metabolic Engineering*, vol. 31, pp. 1–12, 2015.

[20] N. K. Tripathi and A. Shrivastava, "Recent developments in bioprocessing of recombinant proteins: expression hosts and process development," *Frontiers in Bioengineering and Biotechnology*, vol. 7, p. 420, 2019.