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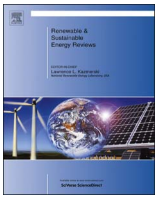

Sustainable and Integrated Bioenergy Assessment for Latin America, Caribbean and Africa (SIByl-LACAf): The path from feasibility to acceptability

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ABSTRACT

Uncertainties in evaluating bioenergy projects have lead policymakers to adopt a restrictive approach or even refuse to evaluate projects when the available information is limited or a clear perception of its benefits and impact is lacking. Indeed, despite its potential advantages, a bioenergy system poses several conceptual and operational challenges for academic as well as practical scrutiny because the inherent relationship and the intersection of areas related to energy production and agricultural activity requires a deeply integrated assessment. The aim of this paper is to review the available works in this field and propose an approach for supporting policymakers in the taking decision process of deploying sustainable bioenergy systems. The SIByl-LACAf framework provides a comprehensive framework for addressing the inherent complexity of the subject and its sustainability and acceptability as part of the evaluation process. With this approach, different and complementary evaluation methods are reviewed and set in a logical and sequential structure to draw a group of indicators used for assessing a given project with the help of a strengths, weaknesses, opportunities, and threats (SWOT) matrix. When acceptability is identified as an issue, a Public Consultation and Communication (PC & C) scheme can complement this process. The suggested application for Mozambique indicate that an acceptable outcome is possible even when considering the data requirements and constraints of developing countries. Thus, the potential of this integrated approach outweighs such limitations.

1. Introduction

Although sustainable bioenergy is recognized as an important energy alternative in global terms, crucial questions have emerged among countries regarding biofuel production. The introduction of fuel ethanol offers good possibilities for greater fuel diversification, lower prices, a cleaner environment, and better social benefits [1]. Based on several climate scenarios, bioenergy will grow to an average of 138 EJ by 2050, representing equivalent to 14% to more than 40% of the projected energy supply. To grow sufficient bioenergy crops for generating 100–200 EJ/year of bioenergy by 2050, about 50–200 million rainfed hectares are needed, corresponding to the use of

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List of Acronyms and Abbreviations: ABM, Agent- Based Model; AGSIM, Econometric-Simulation Model of the Agricultural Economy Used for Biofuel Evaluation; ASEAN, Association of Southeast Asian Nations; BIOTSA, Bioenergy Technology Sustainability Assessment; BLUM, Brazilian Land Use Model; CGE, Computable General Equilibrium; C-LCA, Consequential Life Cycle Assessment; DEPS, GTAP-Dynamic Energy Policy Simulations; FAO, Food and Agriculture Organization of United Nations; GBEP, Global Bioenergy Partnership; GTAP, Global Trade Analysis Project; IA, Integrated Assessment; IC, Inherent Context; IDB, Inter-American Development Bank; IEA, International Energy Agency; ILUC, Indirect Land Use Change; I-O, Input-Output; IS, Innovation System; ISI, Institute for Scientific Information; ISO, International Organization for Standardization; LACAf, Latin America and Africa; LCA, Life Cycle Assessment; LCI, Life Cycle Inventories; LD, Landscape Design; MCA, Multi-Criteria Analysis; OLS, Ordinary Least Square; PC, Perceived Context; PC & C, Public Consultation and Communication; PE, Partial Equilibrium; PLUC, PCRaster Land Use Change; PROMETHEE, Preference Ranking Organization METHod for Enrichment Evaluations; RME, Rape Methyl Ester; SD, System Dynamics; SDSS, Spatial Decision Support Systems; SIByl, Sustainable and Integrated Bioenergy Assessment; S-LCA, Social Life Cycle Assessment; SNA, Social Network Analysis; STELLA, Structural Thinking and Experiential Learning Laboratory with Animation; SWOT, Strenghts, Weaknesses, Opportunities and Threats; UNCTAD, United Nations Conference on Trade and Development; WORLD, Watershed-scale Optimized and Rearranged Landscape Design; GHG, Greenhouse Gas; WoS, Web of Science; WTO, World Trade Organization

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0.4–1.5% of total global land. For an acceptable impact on the environment, the gross demand of land for modern bioenergy and other productive aims is estimated to be between 50 Mha and 200 Mha by 2050 [2]. In this case, the land availability for rainfed agriculture is estimated to be 1.4 Bha of prime and good land and an additional 1.5 Bha of spare and usable marginal land. About 960 Mha of this land is in developing countries in sub-Saharan Africa (450 Mha) and Latin America (360 Mha) although much of it is pasture/rangeland [3]. Thus, special attention must be paid to countries that are able to allocate available land to increase the bioenergy supply in local or international markets. However, each country has inherent peculiarity in terms of soil conditions, the climate for crop production, land availability, infrastructure, economic feasibility, and Available workforce in addition to the institutional framework for developing bioenergy systems, sometimes in scenarios of uncertainty or asymmetric information.

Under such conditions, after an initial positive evaluation, proposals of bioenergy systems may eventually not be acceptable according to the local community perspective or because of other particular aspects. This risk has led policymakers to adopt a restrictive approach or even refuse to evaluate bioenergy projects when the available information is apparently limited or lacks a clear explanation of its benefits and impact.

Despite its potential advantages, however, a bioenergy system poses several conceptual and operational challenges for academic as well as practical scrutiny because the inherent relationship and the overlap of areas and aspects related to agricultural activity and energy production requires a deeply integrated evaluation. Some assessment methods of agricultural and bioenergy systems are currently available. However, considering their environmental, technological, economic, social, and institutional aspects, such methods usually emphasize particular dimensions and do not allow this integration, which is essential for understanding and evaluating the system's sustainability.

The aim of this paper is review the current experience in assessing bioenergy systems and propose a pathway to support policymakers in the taking process of deploying new sustainable bioenergy systems or evaluating existing ones, particularly for developing countries. Considering the usual constraints in the data and information required, a set of evaluation methods is compiled in a logical and sequential structure to draw a set of indicators used for assessing a given project. These indicators are evaluated in a strengths, weaknesses, opportunities, and threats (SWOT) matrix in order to obtain a set of options for evaluating bioenergy projects. If acceptability is an issue, this process can be complemented by a Public Consultation and Communication (PC & C) scheme. This particular approach, the Sustainable and Integrated Bioenergy Assessment for Latin America and Africa (SIByl-LACAf[1]) approach, constitutes a comprehensive framework for addressing the inherent complexity of the subject, and the sustainability and acceptability as part of the evaluation process of bioenergy systems and projects.

This paper is structured in four sections including the introduction. The next section introduces the SIByl-LACAf framework, which includes the essentials of the selected method and the steps in following such an approach. Section 3 gives the suggested steps for a hypothetical application of the SIByl-LACAf framework to Mozambique, and Section 4 presents the main remarks and final considerations.

2. The SIByl-LACAf framework

The literature offers a relatively limited number of methods and analyses related to important aspects of agriculture, particularly bioenergy and biomass and their co-related aspects as environmental, technological, economic, social, and institutional impacts. This lack of information highlights the need to understand sustainability from an integrated perspective. Howells et al. [5] discussed the lack of this type of treatment in recent literature relative to bioenergy, water, land, and climate change. Moreover, they stressed the need for systematic national-level integrated assessment, which differs from traditional practices.

The literature identifies Integrated Assessment (IA) as a reflective and iterative participatory process that links knowledge (science) and action (policy) regarding complex global change issues such as bioenergy production and climate change [6]. Dale et al. [7] reported that significantly fewer studies used IA for bioenergy system approaches than those using isolated approaches for qualitative analysis of indicators used for understanding the socioeconomic factors in such a system. If IA could provide more information than the isolated approach to the scientific field, it will be necessary to understand how this approach can be implemented to significantly improve the analysis for policymakers while supporting the choices among different alternatives [8].

Dowlatabadi et al. [9] and Rotmans et al. [10] defined IA as an interdisciplinary process of combining, interpreting, and communicating knowledge from scientific subjects to evaluate the problem from a synoptic perspective. Moreover, they reported that this process should have added value compared with single disciplinary assessment, and it should provide useful information in the taking process. Leimbach et al. [11] used IA as a common tool for assessing strategies, considering the complex relations among environmental, social, and economic factors.

The present study uses IA to integrate different perspectives of analysis to address this inherent complexity and the inter-relationships discussed by Leimbach et al. [11]. In addition, we determine that technological and institutional aspects must be evaluated. Thus, following Rotmans et al. [10] and Dowlatabadi et al. [9], we propose a more integrated approach in which the data and information, models and methods, and the taking process are part of a full network of relationships [12].

In a network approach, areas and sub-areas are related, which lowers the efforts and costs compared with the necessary time and expense needed for understanding isolated components. For example, to understand the sustainability of a local process, it is more important to understand the connections among environmental, economic, and social aspects than to examine each part individually. The available information or data can contribute to understanding these aspects simultaneously, and the final result will show stronger connections with shared information among these areas.

In this scenario, the implementation process of a sustainable bioenergy system in a specific country involves numerous direct and indirect factors that can result in complexity. The problem begins by defining why, where, and how such a process is implemented. Once the scope of the study is defined, the process of data and information collection is important because they indicate the complexity of the analysis. This step is linked with the chosen framework of analysis: addressing the inherent complexity of information in an integrated approach. The results of the models and methods applied to answer the questions formulated in the objectives, which must be summarized to identify key indicators that accomplish both the investigator taking desision criteria and external sustainable guidance from international agencies such as Global Bioenergy Partnership (GBEP) and Inter-American Development Bank (IDB) Scorecard. Finally, stakeholders such specific agents or make a decision, and the problem is identified.

To explore this process, Fig. 1 summarizes the SIByl-LACAf approach into seven steps: i) definition of objectives, ii) recognizing the complexity of data, iii) addressing the complexity, iv) applying indicators, v) analysis of feasibility, vi) analysis of acceptability, and vii) taking decision.

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[1] The acronym SIByl-LACAf is a tribute to the legend of Greek oracle named Sibyl, represented as an old woman with the ability to make clever and accurate predictions. In this sense, the use of the acronym SIByl to our approach for assessing sustainable projects expresses the intention of traveling through the unknown, connecting elements and arguments to result in correct evaluation [4].

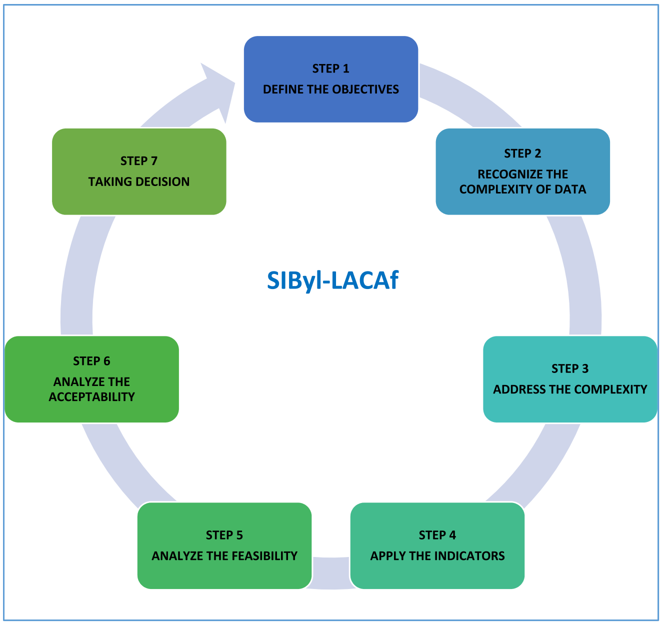

Fig. 1. The structure of the SIByl-LACAf approach
From authors.

The following sections detail each step of the SIByl-LACAf approach.

2.1. Definition of objectives

In this general context, the following questions arise from the SIByl-LACAf approach: (i) the purpose, (ii) the extent, and (iii) the methods used to implement a sustainable bioenergy system. These factors guide the definition of the objectives of analysis.

Variables such as the availability of fertile land with good climate conditions will determine the overall scale of bioenergy production in the next decades, mainly in developing countries. However, it is widely accepted that to increase or introduce the production of bioenergy, a sustainable overview is required that includes social, economic, and environmental impacts. However, a growth in biofuel production is generally believed to have a negative impact on food security, particularly in underdeveloped regions [13].

In addition, some locational peculiarities related to supply and demand in ethanol production must be analyzed in the policymaker's decision process. It is clear that the needs of Africa differ significantly from those of Latin America, and both are distinct of the requirements of Europe and North America. For example, food insecurity is highest in Africa, where hunger persists because of multiple compounding factors such as poverty, poorly developed agricultural infrastructure and support, degraded land, and armed conflicts [13]. The production of biofuels in a sustainable and integrated approach can overcome these factors to provide new solutions. The SIByl-LACAf bioenergy system with systematic analysis is one such approach.

The first step in implementing this method is to clearly define the objectives. The process of information gathering and the selection of models and approaches for discussion ultimately determine the results; the latter is linked directly to the goals listed in the original case.

A range of possible objectives can be chosen by a stakeholder. However, to clearly define the objectives, this paper suggests only two different aims under the scope of stakeholder taking decision: i) Greenfield and ii) Brownfield. A Greenfield project offers opportunities to an investor such as creating an entirely new organization with unique requirements. However, this case implies a gradual market entry owing to the barriers and sunk costs already paid by other firms. Otherwise, an acquisition facilitates quick entry and immediate access to local resources, although the acquired company may require deep restructuring to overcome a lack of fit between the two organizations. In some situations, notably in emerging markets, this restructuring is so extensive that the new operation resembles a Greenfield investment. We term such investment “Brownfield” and present it as a hybrid mode of entry [14]. Once the objectives of analysis are determined, the next step, data and information collecting and processing, is followed.

2.2. Recognizing the complexity of data

As discussed in the Introduction, bioenergy systems involve necessarily several areas of knowledge, which highlights the importance of conducting IA from informational and methodological perspectives. Fig. 2 shows the linkage of different areas of knowledge in a bioenergy system.

The following areas provide information that may be sought to facilitate analysis by the proposed integrated model:

i. Environmental: CO_2 emissions, natural resources use, soil and pastureland management, climate change.
ii. Economic: market clearing, feasibility, productivity, economies of scale, input–output relationship.
iii. Social: skills, work conditions, wages, unions.
iv. Institutional: laws, bureaucracy, government, research institutes.
v. Technological: techniques, innovations, patents, knowledge.
vi. Market for factors: capital, land and labor use.
vii. Market for input: acquiring inputs for agriculture and industry (imports or local, regional, and national).
viii. Market for outputs: selling outputs for external or national markets (exports or local, regional, and national).
ix. Logistics: Distribution logistics of inputs, outputs and infrastructure.

Because the data and information are properly collected, filtered, and stored they can be used in different models and methods, which are described below.

2.3. Addressing the complexity

To address the complexity, the main methods and models are presented following the proposal of an IA approach, which helps to build quantitative and qualitative indicators. It is emphasized that although there is no preferred approach, it is desirable to use a set of methodological approaches. The decision is influenced by whether a sufficient amount of information is available for building a particular model; in addition, a researcher might be more familiar with a particular approach. The purpose of this section is to present solutions compatible with the proposed model and that can assist the researcher in defining the methodology.

Table 1 illustrates that the different methods (i.e. econometric, input-output, and others), independent of hypothesis, have different information such as dependent variables that can be used systematically as an integrated framework. To get the information about each method we have followed the procedure suggested by Antonio de Souza et al. [12] where for each method a search was done in the ISI Web of Science (WoS) database in a way to determine the number of papers related to methods selected and presented in Topic (TS).[2]

For a more detailed overview, Fig. 3 shows the distribution of papers related to bioenergy and the selected methods. The main methods are related to surveys and Life Cycle Assessment (LCA) and Econometric models; no method preference was implied.

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[2] ISI Topic fields include titles, abstracts, keywords, and indexing fields such as systematics, taxonomic terms, and descriptors [15].

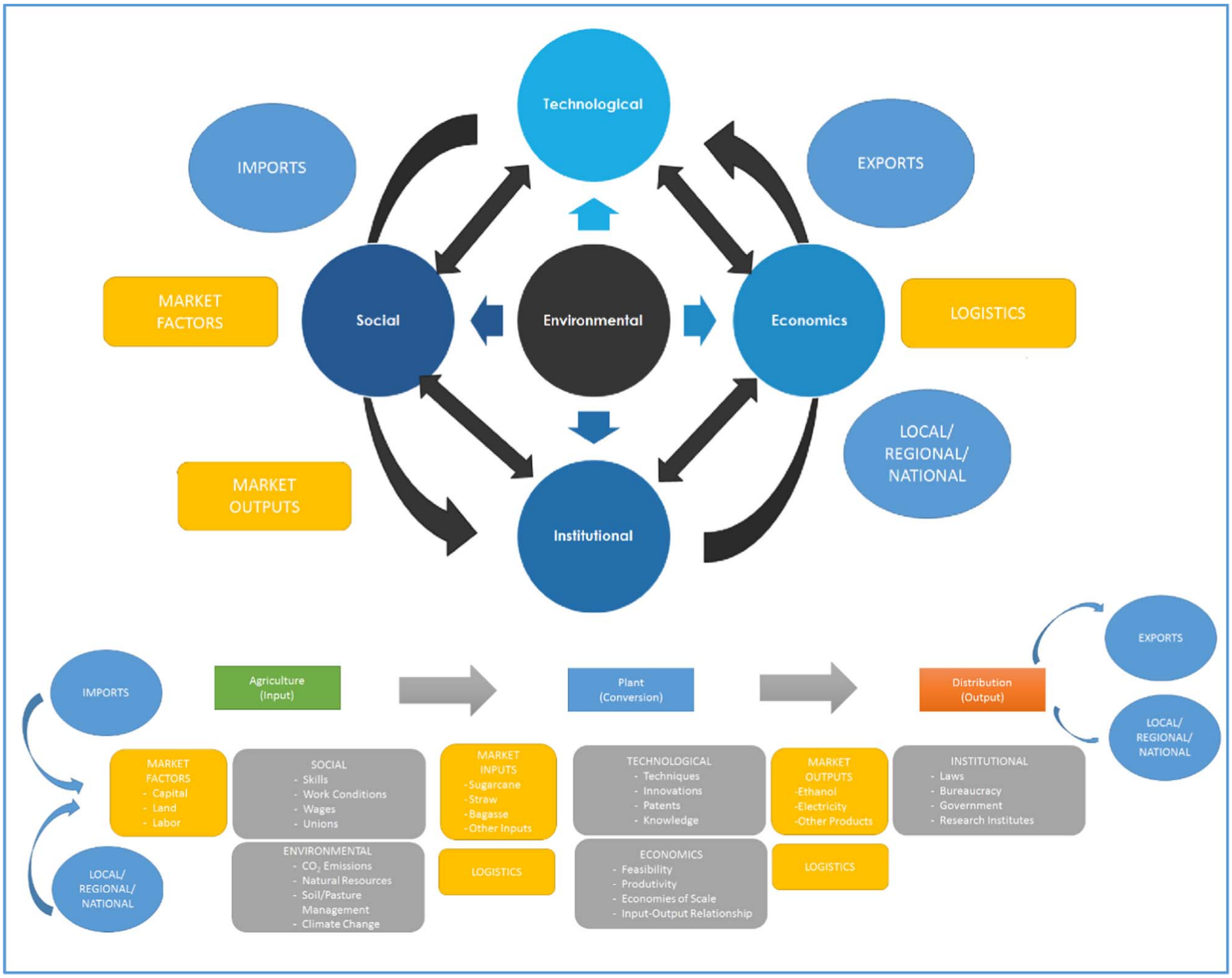

Fig. 2. Recognizing the inherent complexity of data
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Table 1
Methods to deal with the complexity.

Method	Research parameter[a]
Agent-Based Models	TS=(agent NEAR based AND bioenerg[a])
Econometric Models	TS=(econometric AND bioenerg[a]) OR TS=(time NEAR series AND bioenerg[a]) OR TS=(panel NEAR data AND bioenerg[a])
General Equilibrium Models	TS=(general NEAR equilibrium AND bioenerg[a])
Input-Output Analysis	TS=(input-output AND bioenerg[a]) OR TS=(I-O NEAR matrix AND bioenerg[a])
Landscape Design	TS=(landscape NEAR design AND bioenerg[a])
Life-Cycle Assessment	TS=(life-cycle AND assessment AND bionerg[a]) OR TS=(life-cycle NEAR analysis AND bioenerg[a])
Multi-Criteria Analysis	TS=(multi-criteria AND bioenerg[a])
Social Network Analysis	TS=(social NEAR network AND bioenerg[a])
Survey	TS=(survey AND bioenerg[a])
System Dynamics	TS=(system NEAR/1 dynamic AND bioenerg[a])

[a] The Research Parameter follows the procedure of ISI Web of Scince search where TS is a search in topics (title, abstacts, keywords). To a detailed explanation of the procedure see Antonio de Souza et al. [12].

The following sections describe the essentials of the main methods suggested in this step and review some studies and contributions applying them, mainly related to bioenergy systems deployment.

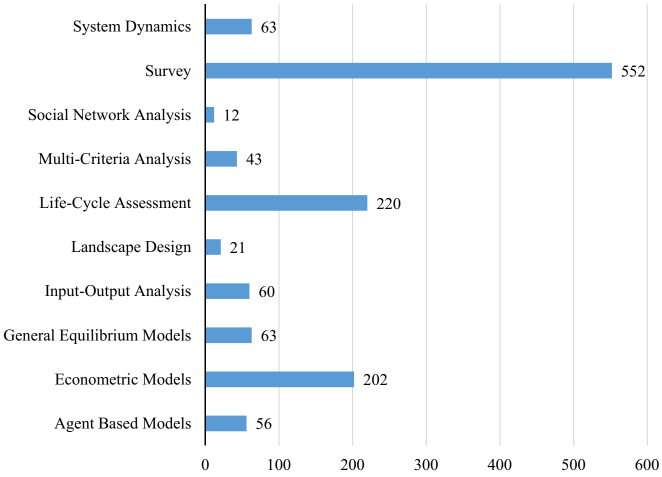

Fig. 3. Number of scientific papers related to bioenergy.
ISI [15]. Obs: The research shows all disposable data until 21 January 2016

2.3.1. Agent-based model

Agent-based modeling (ABM) provides a simulation approach for local-level assessment and considers important micro-level constraints such as environmental externalities, limited adaptive capacity, and behavioral barriers [16,17].

In general, an ABM considers multiple interacting factors (i.e., stakeholders) with two distinct properties: i) the system is composed of interacting agents and ii) the system exhibits emergent properties, that is, properties arising from the interaction of the agents/stakeholders that cannot be deduced simply by aggregating the properties of the agents. The agent-based approach can be used to model the interactions of agents or sub-systems in the biofuel supply chain by using metrics, variables, and indicators as performance measures [8].

An ABM can capture important interactions among different units of a supply chain that contribute to effective taking decision. If the approach is coupled with global dynamic optimization, it can provide rich insight into the key factors that drive the creation and evolution of bioenergy networks [8].

Davis et al. [18] applied the ABM method jointly with LCA to provide environmental information on an evolving energy infrastructure system. An ABM has the technology to enable owners to make decisions based on economic and environmental information. This approach allows exploration of the dynamics of assembly and disassembly, which are used to analyze the effects of using LCA information in taking decision.

Berger et al. [17] showed that ABM is well suited for uncertainty analysis and can complement existing simulation approaches to advance the understanding and implementation of effective climate-related policies in agriculture. Troost et al. [19] employed a farm-level ABM model to analyze the reaction of a heterogeneous farming population in Southwest Germany to the incentives set by the German Renewable Energy Act (EEG) and the Marktentlastungs- und Kulturlandschaftsausgleich (MEKA) agri-environmental policy scheme.

Ng et al. [20] developed an ABM for farmers' crops and best management practice decisions linked to a hydrologic–agronomic model of a watershed to examine farmer behavior and the attendant effects on stream nitrate load under the influence of markets on conventional crops, carbon allowances, and a second-generation biofuel crop. Their approach introduced interactions among farmers concerning new technologies and market opportunities and included updating of forecast expectations and uncertainties by using Bayesian inference.

Shastri et al. [21] used an ABM to study the system dynamics in biomass feedstock production. In their approach, farmers and the biorefinery were modeled as independent agents. Taking decision of each agent, as well as its interaction with other agents, was modeled by using a set of rules reflecting the economic, social, and personal attributes of the agent.

Van Vliet et al. [22] formalized and parameterized an ABM for the production of 6 transport fuels and 6 fuel blends from 6 feedstocks through 13 different production chains in addition to their adoption by 11 distinct subpopulations of motorists. The motorists were represented by agents that used heuristics to choose a fuel on the basis of three attributes and a social feedback loop. Their main results showed that adoption of specific fuels is mostly driven by price differences, although other factors are considered if prices are similar.

Verstegen et al. [23] used Spatial Decision Support Systems (SDSSs) for a case study of changing land availability for bioenergy crops in Mozambique. The proposed PCRaster Land Use Change (PLUC) model integrated simulation, uncertainty analysis, and visualization. The results enabled evaluation where bioenergy crops can be cultivated without endangering nature in addition to actual food production in the near future when population and food intake per capita will increase and thus arable land and pasture areas are likely to expand.

2.3.2. Econometric model

Econometric analysis[3] is used to develop, estimate, and evaluate models that relate economic or financial variables. An applied economic study usually proceeds with the following steps:

i. Providing a statement of theory or hypothesis. This step requires economic expertise.
ii. Specification of the econometric model to test the theory among linear or non-linear, univariate or multivariate, and single or multiple equations.
iii. Estimation of the parameters of the chosen model, whether parametric or non-parametric.
iv. Classical or Bayesian estimation.
v. Evaluation by diagnostic tests, ex-post forecasting, and simulations.
vi. Application of the model for control, forecasting, or policy purposes.

Econometric methods guide the applied economist through these steps. The development of econometric methods has proceeded at an unprecedented rate over the last 40 years, spurred along by advances in computing, econometric theory, and the availability of richer datasets [25].

Seyffarth [26] used the econometric approach in a controversial debate on the impacts of rising biofuel production on food commodity markets, which is of great policy relevance in Brazil. Such research applied a panel data regression model with fixed effects using ordinary least squares (OLS). The result indicated that rising ethanol production exerts statistically significant positive impacts on sugarcane agroindustry.

Taylor et al. [27] used the Econometric Simulation model of the Agricultural Economy Used for Biofuel Evaluation (AGSIM) to evaluate the economic impacts of the simulation model for the United States agricultural economy. This simulation model is based on a large set of econometrically estimated dynamic demand and supply equations for major field crops produced in the United States.

Clancy et al. [28] examined the socioeconomic factors affecting the willingness to adopt bioenergy crops in Ireland. In their study, the Probit model was used to determine the extent to which these selected characteristics influence the willingness of farmers to consider alternative cropping systems. In the final model specification, farm profit, land tenancy, general education level of the farm operator, contact with extension agents, and age of the operator were shown to be insignificant variables affecting the willingness to adopt.

Serra [29] used time-series econometrics to analyze the volatility interactions between biofuel and food and fossil fuel markets. In this sense, Figueira et al. [30] forecasted fuel ethanol consumption in Brazil by using a time series model for the 2006–2012 period.

Powell et al. [31] analyzed the wheat yield changes in Europe and the resulting economic consequences in the near to medium-term future. The results addressed the effects of yield changes on land use, and the transition and growth of yields were estimated by using a combination of convergence, time-series, and dynamic panel models. Scenarios were then run using estimated yields as input into a Computable General Equilibrium (CGE) model.

Ding et al. [32] modeled the link among biodiversity, ecosystem services, and human wellbeing in the context of climate change from the results of an econometric analysis of European forest ecosystems.

Couture et al. [33] proposed an econometric analysis of household fuelwood demand in France. The choice concerning the energy used for heating was modeled, stressing the combination of one type of energy used as the main source and another used as back-up. This endogenous decision had an impact on fuelwood consumption, which was considered to avoid biased estimates of price and income elasticities.

Anderson [34] estimated the household preferences for ethanol (E85) as a gasoline (E10) substitute through a theoretical model linking the shape of the ethanol demand curve to the underlying distribution among households showing willingness to pay for ethanol.

Bayramoglu et al. [35] used an individual panel data approach to measure the indirect effect of biofuel policies in France. Their model tested the hypothesis that pesticide demand rises when the price

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[3] Greene [24].

increases for rapeseed, which is the principal feedstock for the production of biodiesel in France.

Hatirli et al. [36] used the econometrics approach to analyze the energy use and investigated the influences of energy inputs and energy forms on the output levels of Turkish agriculture during the period 1975–2000.

2.3.3. General Equilibrium model

CGE and Partial Equilibrium (PE) models have recently been used for assessing the likely impacts of climate-related policy interventions on agricultural production [17]. The General Equilibrium model (GEM) can be used mainly as a tool for impact analysis under economics, environmental, social, technological, and institutional considerations.

Regardless of the type of problem selected for analysis, the following specifications must be considered in any modeling process:

i. The number and type of goods such as consumer goods, production goods, and primary factors.
ii. The number and type of consumers, possibly classified by income, age, qualifications, and preferences.
iii. The number and type of firms or productive sectors such as simple or joint production, type of revenue of the production functions, and technological development.
iv. The characteristics of the public sector such as attitude of the government as the buyer or producer, fiscal system, and budget.
v. The characteristics of the foreign sector including related enterprises and sectors, the degree of international integration; established tariffs, and customs duties.
vi. The concept of equilibrium with or without unemployment and with or without public or foreign deficit.

The choice of these specifications will determine the particular output of the model to be used. However, the theoretical refinement of the model will also be affected by practical constraints such as information availability. That is, an applied GEM involves a trade-off between the researcher's intent to represent the economy's structure and the ad hoc constraints set by the available statistical information [37].

Dandres et al. [38] described a tool for assessing the medium- and long-term economic and environmental impacts of large-scale policies. A GEM known as the Global Trade Analysis Project (GTAP) was therefore used to simulate the economic effects of policies in a dynamic framework representing the temporal evolution of macroeconomic and technological parameters. Environmental impacts, expressed by four indicators including human health, ecosystems, global warming, and natural resources, were computed according to the policy life cycle and its indirect economic effects.

Oladosu et al. [39] compared the allocation of land in the GTAP–Dynamic Energy Policy Simulations (DEPS) model with the regional allocation in the Brazilian Land Use Model (BLUM), where the former is a global GEM that incorporates cellulosic biofuels, dynamics, and other enhancements to enable simulation of the evolution and impacts of policy, and the latter is a partial equilibrium model for evaluating the land use change impacts of biofuel in Brazil. The purpose of their study was to evaluate the prospects for interactions between the two models and to determine how to translate the input–output (I–O) from one model to the other in simulating the effects of biofuel production on land use change in Brazil.

Ferreira Filho et al. [40] evaluated ethanol expansion and indirect land use change (ILUC) in Brazil by using an inter-regional, bottom-up, dynamic GEM calibrated with the 2005 Brazilian (I–O) table. A new methodology to address the ILUC effects was developed that uses a transition matrix of land use calibrated with Agricultural Census data. Agriculture and land use were modeled separately in each of 15 Brazilian regions with different agricultural mixes. The regional detail captured substantial differences in soil, climate, and history that caused particular land to be used for particular purposes.

Arndt et al. [41] made a CGE analysis of Mozambique to evaluate the interactions among agricultural technology improvements, risk-reducing behavior, and gender roles in agricultural production. The analysis explicitly incorporated key features of the economy such as marketing margins, home consumption, risk, and gender roles in agricultural production.

2.3.4. Input–output

I–O analysis is widely applied to conduct national economic analyses and structural research and to assess macroeconomic impacts of bioenergy production [42,43]. The methodology allows for evaluating the impacts of new economic activities on a regional or national economy by using I–O tables. These tables represent annual monetary flow of goods and services among different sectors of the economy.

This methodology enables a snapshot of the economy to be captured by exposing the intra- and inter-sectoral factors representing one side of input suppliers, where sector i produces intermediate inputs for different industries and other buyers, and sector j purchases inputs from different industries to produce one unit of output. In this method, some interdependence between flows is indicated. Also examined in this method is a portion of the final demand, such as household consumption, government investment, and exports, which is considered exogenous to the model [43,44].

One essential set of data for an I–O model includes the monetary values of the transactions between pairs of sectors (from sector I to sector j) representing its origin and destination with the variable z_{ij}. In addition, in any country, sales are made to purchasers who are more external or exogenous to the industrial sectors such as households, government, and foreign trade, constituting the producers in the economy. The demand of these external units is generally referred to as final demand [43].

In the I–O approach, a fundamental assumption is that interindustry flows from i to j for a given period such as one year and depends entirely on the total output of sector j for that same time period. For example, the ratio between z_{ij} and x_j for a specific year is referred to as a technical coefficient a_{ij}, which represents the amount of inputs from sector i required to produce a unit of final product of sector j. The a_{ij} coefficient measures fixed relationships between a sector's output and its input. Economies of scale in production are thus ignored; production in a Leontief system operates under constant returns to scale [43].

Martínez et al. [45] used I–O analysis to determine the impacts of sustainable sugarcane ethanol production on the gross domestic product (GDP), employment, and imports in the northeast region of Brazil. The use of an extended inter-regional I–O model can quantify direct and indirect socioeconomic effects at the regional level and can provide insight into the linkages among regions. The application of the model to Northeast Brazil demonstrated significant positive socioeconomic impacts that can be achieved when developing and expanding the sugarcane–ethanol sector in the region under the conditions studied here not only for this region itself but also for the economy the entire country.

Baral et al. [46] demonstrated the use of a thermodynamically augmented economic I–O model of the U.S. economy for obtaining sector-specific emergy (a thermodynamic propertie) to money ratios that can be used instead of a single ratio. In their study, a hybrid approach to emergy analysis was introduced and compared with conventional emergy analysis using life cycles of corn ethanol and gasoline as examples. By comparing sector-specific emergy/money ratios with those from the conventional emergy study, it was verified that the I–O model can provide reasonable estimation for transformations, at least as a stop-gap measure until more detailed analysis is completed.

You et al. [47] analyzed the optimum design of sustainable cellulosic biofuel supply chains through multi-objective optimization under economic, environmental, and social objectives coupled with I–O Analysis and LCA.

Watanabe et al. [48] used a hybrid approach combining LCA and I–O analysis to demonstrate the economic and environmental benefits of current and future improvements in agricultural and industrial technologies for ethanol production in Brazilian biorefineries.

Souza et al. [49] developed quantitative social metrics to evaluate different technological ethanol production systems in Brazil. Their study showed the outcome of a novel hybrid approach integrating Social Life Cycle Assessment (*s*-LCA) and I–O analysis.

Burnquist et al. [50] estimated an interregional I–O matrix for the Brazilian economy to evaluate the impact of an increase in Brazilian sugar and ethanol demand for exports on the country's overall production and employment.

Cruz et al. [51] presented a novel multi-time stage I–O-based modeling framework for simulating the dynamics of bioenergy supply chains. One of the key assumptions in their method is that the production level at the next time stage of each segment of the energy supply chain adjusts to the output surplus or deficit relative to the targets at the current period.

Arndt et al. [52] used the Social Accounting Matrix approach, which has the same scope as the I–O approach, to evaluate the structural characteristics of the Mozambique economy. In this sense, Kunimitsu et al. [53] analyzed the economic ripple effects of bioethanol production in countries belonging to the Association of Southeast Asian Nations (ASEAN) through the application of inter-regional I–O analysis.

2.3.5. Landscape design

Levinthal et al. [54] reported that management literature has increasingly emphasized the importance of self-organization and local action. Indeed, self-organization does not negate the possibility of design influences; thus, a new set of design tools or concepts may be useful. From this perspective, landscape design (LD) has emerged as the tuning of fitness landscapes upon which actors adapt. Actors adapt not only to fixed landscapes but also to surfaces that are deformed by others actions.

Makhzoumi et al. [55] identified physical, biological, and anthropic factors as three main components used in determining landscape, the interrelations of which continuously compose the landscape.

In fact, an increase in bioenergy usage and production will have interdependent environmental and socioeconomic impacts. Several technological pathways connect the various biomass sources to diverse forms of bioenergy such as fuel, heat, and power. Currently, the complexity and scale dependency of such decisions and their impacts are not understood, defined, or described with adequate clarity to enable policymakers to develop strategies for ensuring a sustainable bioenergy future with acceptable environmental and socioeconomic consequences, particularly under a changing climate regime.

The LD approach considers the effects of interventions and conditions at different spatial scales on the outcomes. Moreover, it demonstrates how this approach addresses biofuel selection and deployment. These objectives can be addressed through three tasks: 1) development of a systems-based conceptual model of the key environmental implications of bioenergy choices, 2) development of a geospatial information systems framework in which the conceptual model can be implemented, and 3) identification of susceptible points in the conceptual model via spatial optimization.

Dale et al. [56] used LD to develop scenarios with stakeholders for a defined spatial and temporal context and to evaluate the best available science, data, and tools of LD that best meet multiple development goals. As a result, they proposed the following action areas: i) stakeholder engagement in the southeast forestry sector, ii) certification, iii) market stability, iv) planning and guidance tools, and v) analysis tools.

Venema et al. [57] applied LD to a rural bioenergy planning framework based on location–allocation and landscape ecology principles. The framework considered both domestic and commercial energy demands and energy flow as well as the landscape impact of the required bioenergy production zones.

Eranki et al. [58] evaluated the watershed-scale optimized and rearranged LD (WORLD) model to estimate land allocations for different cellulosic feedstocks at the biorefinery scale without displacing current animal nutrition requirements. The model also incorporated a network of the aforementioned depots.

Brooker [59] developed an application of focal species knowledge to LD in agricultural lands by using an ecological neighborhood as a template.

Lovell et al. [60] integrated agroecology and landscape framework to evaluate the design of agroecosystems. They considered how agroecosystems might be designed to incorporate additional functions while adhering to agroecology principles for managing the landscape. The framework included an assessment tool for evaluating farm design based on the extent of fine-scale land use features and their specific functions to consider the state of the farm.

2.3.6. Life Cycle Assessment

LCA is a methodological approach used to support decisions in a wide range of applications at society, company, and consumer levels, assessing the explicit and implicit impacts of a given process or product, “from the cradle to the grave”. The main requirement for LCA is that the system models behind the inventory reflect the environmental consequences of the decision regarding the actual difference in inputs and outputs from the industrial systems affected when choosing one alternative over another [61].

LCA also follows internationally accepted methods (ISO 14040 and ISO 14044) and practices used to evaluate the requirements and impacts of technologies, processes, and products to determine their propensity to consume resources and generate pollution. The analysis involves four phases: i) objectives and scope definition, ii) life cycle inventory analysis, iii) evaluation of life cycle environmental impacts, and iv) interpretation of the results [8,62].

Cherubini et al. [63] made an extensive review on LCA for bioenergy systems in studies that addressed different biomass resources, conversion techniques, products, and environmental impact categories. Their research gave a qualitative interpretation of the LCA results with a focus on energy balance, greenhouse gas (GHG) balance, and other impact categories.

McKone et al. [64] identified challenges in using LCA to evaluate the environmental footprint of biofuel alternatives and to support the evolving bioeconomy. The main challenges include i) understanding feedstock growers, options, and land use; ii) predicting biofuel production technologies and practices; iii) characterizing tailpipe emissions and their health consequences; iv) incorporating spatial heterogeneity in inventories and assessments; v) temporal accounting in impact assessments; vi) assessing transitions and end states; and vii) addressing uncertainty and variability.

Kaltschmitt et al. [65] discussed a methodological approach for conducting LCA for biofuels in a case study of rape methyl ester (RME) compared with diesel fuel. Their approach was also applied to bioenergy routes in Germany. In this direction, Davis (2009) reviewed a main study that applied LCA to biofuel feedstocks in which the efficiency and GHG impact of energy systems was assessed.

Dressler et al. [66] evaluated the parameters influencing the results of LCA on biogas production from maize and the conversion of biogas into electricity. The environmental impacts of biogas varied according to regional farming procedures and therefore soil, climate conditions, crop yield, and cultivation management. Their study focused on these regional parameters and the existing infrastructure, including the number of installed biogas plants and their share of used heat.

Gnansounou et al. [67] focused on significant biases in estimating GHG balances of biofuels stemming from modeling choices related to system definition and boundaries, functional units, reference systems, and allocation methods. In this direction, they evaluated LCA of wheat-to-bioethanol as an illustrative case in which bioethanol was blended with gasoline at various percentages (E5, E10 and E85). Their results showed a large difference in the reduction of GHG emissions with high sensitivity to the following factors: the method used to allocate the impacts of the co-products, the type of reference system, the choice of the functional unit, and the type of blend.

Botha et al. [68] made a comparison of the environmental benefits of bagasse-derived electricity and fuel ethanol on a life cycle basis using South African data. The results confirmed that for all impact categories considered, both bioenergy products resulted in environmental benefits.

Luo et al. [69] conducted comparative LCA on gasoline and ethanol as fuels based on two types of gasoline and bioethanol blends used in a mid-sized car. Their focus was on sugarcane-based ethanol, which is the main application in Brazil.

Khatiwada et al. [70] performed LCA to evaluate the energy inputs (resource consumption) and GHG balances (climate change impact) in an ethanol production chain from cane molasses in Indonesia.

Marvuglia et al. [71] modeled Consequential Life Cycle Assessment (C-LCA) for bioenergy. Although the conventional Life Cycle Inventories (LCIs) are static models and do not consider mechanisms of profit maximization and equilibrium at the price market, the relationships between the activities and processes in C-LCA are not just connections. Instead, socioeconomic mechanisms are considered through market factors of partial or general equilibrium. In their study, this approach was applied to evaluate biogas production in Luxembourg with particular emphasis on ILUC.

2.3.7. Multi-criteria analysis

Multi-criteria analysis (MCA) can be defined as a formal approaches that explicitly considers multiple criteria in helping individuals and groups to explore important decisions [72]. MCA stands in contrast to single goal optimization and approaches that use “unifying units” to offset poor performances of one criterion by relying of good performances of another criterion, as is included in cost-benefit analysis using monetary values assigned to parameters, therefore allowing for substitution and compensability between criteria.

Buchholz et al. [72] applied the MCA to Uganda in order to facilitate the design and implementation of sustainable bioenergy projects with a special focus on multi-stakeholder inclusion. Although it contributes to only part of the comprehensive taking decision process, MCA can assist in overcoming implementation barriers by i) structuring the problem, ii) assisting in the identification of the least robust or most uncertain components in bioenergy systems, and iii) integrating stakeholders into taking decision process. These tools resulted in a large variability of outcomes in their study. However, all tools were important in making a bioelectricity project viable by consistently identifying the social criteria.

Elghali et al. [73] developed an approach for establishing a sustainability framework for assessing bioenergy systems to provide practical advice for policymakers, planners, and the bioenergy industry, thus supporting policy development and bioenergy deployment at different scales. Their approach used MCA and decision conferencing to explore the manner in which such a process is able to integrate and reconcile the interests and concerns of diverse stakeholder groups.

Scott et al. [74] considered that bioenergy schemes are naturally multi-faceted and complex and include many available raw material supplies and technical options and a diverse set of stakeholders holding numerous conflicting opinions. From this perspective, they made an important review of multi-criteria taking decision methods of bioenergy systems in addressing the correlated problems that arise within this sector.

Beccali et al. [75] offered an application of the multi-criteria taking decision methodology to assess an action plan for the diffusion of renewable energy technologies at the regional scale. Their methodological tool gives the decision maker considerable help in the selection of the most suitable innovative technologies in the energy sector according to preliminarily fixed objectives.

Rozakis et al. [76] integrated microeconomic modeling and multi-criteria methodology to support public taking decision in the case of liquid biofuels in France, where a tax credit policy is determined in the French biofuel industry producing ethanol and esters. In their study, microeconomic models simulated the agricultural sector and the biofuel industry through multi-level mixed-integer linear programming.

Ren et al. [77] conducted multi-criteria evaluation for the optimal adoption of distributed residential energy systems in Japan. A set of residential energy alternatives, including both conventional energy and renewable energy applications, were assumed for adoption. The main results showed that currently, renewable energy systems are not competitive unless strong attention is paid to the environmental benefits.

Oberschmidt et al. [78] used the modified Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) approach to offer a multi-criteria methodology for the performance assessment of energy supply technologies. Their method also considered the dynamics of technological change.

Terrados et al. [79] focused on the exploitation of renewable resources, particularly solar and biomass energy, which highlighted the effectiveness of techniques of business management applied to a sustainable energy model design. They used combined MCA that incorporated techniques from strategic analysis with SWOT analysis. In their study, the SWOT analysis proved to be an effective tool and constituted a suitable baseline for diagnosing current problems and sketching future action lines.

2.3.8. Social network analysis

Antonio de Souza et al. [12] highlights that the Social Network Analysis (SNA) emerged from the graph theory and have a graph or network composed by the following basic elements:

i. Nodes, which are people or groups of people who come together with a common goal. Visual representation in the units of analysis can be actors, elements, countries, research institutes, companies, associates, papers, or other elements.
ii. Edge, which indicate the interactions or links between two or more nodes, i.e., connecting two adjacent vertices. In a network with n players, one particular node can have $(n - 1)$ links.
iii. Flow, which indicates the direction of the bond by using an arrow that may be unidirectional or bidirectional.

From the networks created with a specific objective, the following indicators for a network that requires further interpretation can be obtained:

i. Average Geodesic Distance: The geodesic distance (or social distance) is an indicator of network cohesion and is defined as a minimum number of links (or edges) that separates two distinct actors in a network.
ii. Average Density: The density of the network indicator measures the relative amount of existing connections; this also indicates network cohesion. Networks are considered to be dense (sparse) if a large (small) number of links exists between actors.
iii. Average Centrality Degree: The centrality measures assist in verifying the relative importance of a vertex in a network. In this case, this indicator is specific and allows verification of the centrality of the actors. The degree of centrality measures the number of actors to which an actor is directly linked.

As shows in Fig. 3, few specialized studies discuss the application of SNA to a bioenergy theme. The main approach was reported by Souza et al. [12], who applied the bibliometric plus scientometric approach to second-generation ethanol.

2.3.9. Survey approach

Surveys provide a means of measuring a population's characteristics, self-reported and observed behavior, awareness of programs, attitudes, opinions, and needs. Repeating surveys at regular intervals can assist in the measurement of changes over time. These types of information are invaluable in planning and evaluating government policies and programs. Unlike a census, in which all members of a population are studied, sample surveys gather information from only a portion of a population of interest. The size of the sample depends on the purpose of the study.

In a statistically valid survey, the sample is objectively chosen so that each member of the population will have a known non-zero chance of selection. Only then can the results be reliably projected from the sample to the population. The sample should not be selected haphazardly or only from those who volunteer to participate.

Buchholz et al. [80] applied a survey for many countries to analyze how key experts perceive the 35 sustainability criteria for bioenergy found in emerging sustainability assessment frameworks and to identify levels of agreement and uncertainty. Experts were asked to rate the criteria for attributes of relevance, practicality, reliability, and importance. A population of 137 bioenergy experts was identified as key participants in the current bioenergy debate with specific attention given to a range of experience in regions, types of bioenergy systems, scale of operation, and profession.

For Mooney et al. [81], the second-generation bioenergy feedstocks are poised to become a key component of the nation's agricultural and energy sectors, yet few studies have examined farm supply response using survey information. Therefore, they used contingent valuation data from farmers in southwestern Wisconsin to develop ex-ante supply estimates for two prospective feedstocks, corn stover and switchgrass, in terms of the farmers' extensive and intensive acreage decisions.

Altman et al. [82] evaluated the willingness to supply biomass for bioenergy production through random parameter truncated analysis based on data from two biomass producer surveys collected from Mid-Missouri and Southern Illinois.

Stefanelli et al. [83] analyzed the green supply chain management and environmental performance of firms through a survey conducted on 80 micro, small, and medium-sized firms that supply the Brazilian bioenergy sector including sugarcane and ethanol production.

2.3.10. System dynamics

The system dynamics (SD) approach is a well-established system perspective/complexity science method originally developed by Jay Forrester at the Massachusetts Institute of Technology (MIT) [84,85]. This method has been applied in various corporate, industrial, and government decisions worldwide for modeling and understanding the interrelationships (i.e., feedbacks) of variables, indicators, and metrics over time.

SD has been useful in modeling the interrelationships between or among sub-systems that are linked by variables and aids in determining how such interlinkages will produce specific overall system behavior. Before using an appropriate modeling software package, it is important to draw causal loop diagrams. A causal loop diagram is a visual representation of the feedback loops in a system whereby the stocks and flows involving different variables, parameters, and indicators are connected by either positive or negative loops. A stock (e.g., biomass, GHG, revenue, or unemployment) is the term for any entity in the system that accumulates or depletes over time. A flow is the rate of change in a stock; the flow changes the rate of accumulation of the stock.

Musango et al. [86] suggested that the SD approach is best suited for assessing the sustainability of technologies with a specific emphasis on policy interventions for renewable energy in the African context. A Bioenergy Technology Sustainability Assessment (BIOTSA) model was demonstrated by analyzing the outcomes in their study.

Ouyang et al. [87] developed an SD model to estimate the hydrological processes and water use in a eucalyptus urophylla plantation by using Structural Thinking and Experiential Learning Laboratory with Animation (STELLA) software.

Martinez-Hernandez et al. [88] evaluated the impact of bioenergy production on ecosystem dynamics and services in Heathlands, U.K., whereas Barisa et al. [89] used SD to analyze future biodiesel policy designs and consumption patterns in Latvia.

Miller et al. [90] used a stochastic approach to model dynamic systems in LCA. In their opinion, LCA can be made more robust and dynamic by using the related framework to couple scenario modeling with life cycle data by analyzing the effects of taking decision patterns over time. Potential uses of the proposed model include examining the changing urban metabolism of growing cities, understanding the development of renewable energy technologies, identifying transformations in material flows over space and time, and forecasting industrial networks for developing products.

Shastri et al. [21] modeled SD through the development and application of an ABM by using the theory of complex adaptive systems. Farmers and the biorefinery, two key stakeholders in the system, were modeled as independent agents. The taking decision of each agent, as well as its interaction with other agents, was modeled by using a set of rules reflecting the economic, social, and personal attributes of the agent.

Cruz et al. [51] used the SD framework for developing a novel multi-time I–O-based modeling framework for simulating the dynamics of bioenergy supply chains. One of the key assumptions used in the model is that the production level at the next time stage of each segment of the energy supply chain adjusts to the output surplus or deficit relative to targets at the current time period.

In this section, we have shown the main methods and approaches that were applied in a single or integrated way (Table 2). In fact, some applications used two or three methods, although not in the sense suggested here.

Indeed, the literature review highlights the scarcity of integration among methods to support taking decision; this gap is one point that needs improvement. SIByl-LACAf can be employed to more effectively use the data and information of previously step through a sort of methods that can talk direct or indirectly. Addressing the complexity step is crucial because the output, or the indicators, drive the policy-maker to make the final decision.

2.4. Applying indicators

Indicators that measure parameters occurring before or after an event are essential for integrated analysis of bioenergy systems. Lying at the intersection of energy and agricultural activity, bioenergy systems are related to activities having important socioeconomic and environmental sustainability repercussions. Bioenergy is, therefore, an inherently interdisciplinary subject and requires a multidisciplinary framework of analysis for proper evaluation.

As suggested in Section 2.2, analysis of bioenergy systems needs to consider agricultural, environmental, economic and social aspects in addition to technological and legal/institutional factors. Effective indicators can help to identify and quantify the multivariate attributes of bioenergy options. However, in the process of developing and using criteria and indicators, the limitations of data and modeling deserve careful attention.

In fact, the methods and models previously discussed can offer a scientific procedure for addressing data and disposable information with direct evaluation of uncertainty. Nevertheless, the output of such a procedure must be more analytical than complex. Otherwise, the stakeholder difficulty will find a solution to the problem. The raw

Table 2
Example of bioenergy studies dealing with the complexity.

Method	References
Agent-Based Model (ABM)	Bonabeau [16]; Berger et al. [17]; Halog et al. [8]; Davis et al. [18]; Troost et al. [19]; Ng et al. [20]; Shastri et al. [21]; Van Vliet et al. [22]; Verstegen et al. [23]
Econometric Model	Seyffarth [26]; Taylor et al. [27]; Clancy et al. [28]; Serra [29]; Figueira et al. [30]; Powell et al. [31]; Ding et al. [32]; Couture et al. [33]; Anderson [34]; Bayramoglu et al. [35]; Hatirli et al. [36]
General Equilibrium Model (GEM)	Berger et al. [17]; André et al. [37]; Dandres et al. [38]; Oladosu et al. [39]; Ferreira Filho et al. [40]; Arndt et al. [41]
Input-Output Analysis (I-O)	Herreras Martínez et al. [42]; Baral et al. [46]; You et al. [47]; Watanabe et al. [48]; Souza et al. [49]; Burnquist et al. [50]; Cruz et al. [51]; Arndt et al. [52]; Kunimitsu et al. [53]
Landscape Design (LD)	Levinthal et al. [54]; Makhzoumi et al. [55]; Dale et al. [56]; Venema et al. [57]; Eranki et al. [58]; Brooker [59]; Lovell et al. [60]
Life Cycle Assessment (LCA)	Wenzel [61]; Souza [62]; Cherubini et al. [63]; McKone et al. [64]; Kaltschmitt et al. [65]; Davis et al. [18]; Dressler et al. [66]; Gnansounou et al. [67]; Botha et al. [68]; Luo et al. [69]; Khatiwada et al. [70]; Marvuglia et al. [71]
Multi-Criteria Analysis (MCA)	Buchholz et al. [72]; Elghali et al. [73]; Scott et al. [74]; Beccali et al. [75]; Rozakis et al. [76]; Ren et al. [77]; Oberschmidt et al. [78]; Terrados et al. [79]
Social Network Analysis (SNA)	Antonio de Souza et al. [12]
Survey Approach	Buchholz et al. [80]; Mooney et al. [81]; Altman et al. [82]; Stefanelli et al. [83]
System Dynamics (SD)	Borshchev et al. [85]; Sterman [84]; Musango et al. [86]; Ouyang et al. [87]; Martinez-Hernandez et al. [88]; Barisa et al. [89]; Miller et al. [90]; Shastri et al. [21]; Cruz et al. [51]

indicators from methods application can be categorized into two main classes: qualitative and quantitative. This study proposes criteria for selection or use of this indicator in performing feasibility and acceptability analysis.

Dale et al. [91] summarized an analysis of existing indicators in the literature for sustainability, beginning with the selection and identification of key criteria. In their opinion, the indicator must have the following characteristics:

i. Practicality.
ii. Sensitivity and responsiveness to both natural and anthropogenic stresses to the system.
iii. Clarity with respect to what is measured, how measurements are made, and how response is measured.
iv. The ability to anticipate impending changes.
v. The ability to predict changes that can be averted with management action.
vi. Estimation capacity with known variability in response to changes.
vii. Sufficiency when considered collectively.

In terms of structure, comparisons frequently use standards for building and analyzing the indicators following international agency guidelines. In bioenergy and related areas, the main set of structured indicators follows GBEP.

GBEP combines public, private, and civil society stakeholders in a joint commitment to promote bioenergy for sustainable development. The partnership focuses its activities on three strategic areas: sustainable development, climate change, and food and energy security. The GBEP sustainability indicators for bioenergy were developed by GBEP partners and observers through the GBEP Task Force on Sustainability organized in the United Kingdom in 2008 and under the leadership of Sweden since October 2010. The task force report presents 24 voluntary sustainability indicators for bioenergy that are intended to guide bioenergy analysis undertaken at the domestic level by assisting taking decision and facilitating the sustainable development of bioenergy. Accordingly, these indicators shall not be applied so as to limit trade in bioenergy in a manner inconsistent with multilateral trade obligations. In addition, supporting information related to the relevance, practicality, and scientific basis of each indicator, including suggested approaches for their measurement, are presented in the methodology sheets.

Table 3 summarizes the indicators suggested by GBEP [92] in the three main areas of environmental, social, and economic perspectives.

The present research does not suggest simply following GBEP [92] or other recommendations of good practices in indicators. Rather, the use of qualitative and quantitative indicators from the methods output is advised to clearly determine the most appropriate indicators. Fig. 4 shows how the output can be allocated in a structured way in agreement with GBEP [92] or other suggested lists of categories. The final set of indicators will drive the stakeholder to the next step, to answer the main question: is that project feasible? If the output is unclear, the interpretation can be more difficult. Thus, in addition to face the complexity and gather sound data and information, a consistent feasibility analysis should be done, as discussed in the following section.

Table 3
GBEP Sustainability Indicators for Bioenergy.
Source: GBEP [92].

Environmental	Social	Economic
Life Cycle GHG emissions	Allocation and tenure of land for new bioenergy production	Productivity
Soil quality	Price and supply of a national food basket	Net energy balance
Harvest levels of wood resources	Change in income	Gross value added
Emissions of non-GHG air pollutants, including air toxics	Jobs in the bioenergy sector	Change in consumption of fossil fuels and traditional use of biomass
Water use and efficiency	Change in unpaid time spent by women and children collecting biomass	Training and re-qualification of the workforce
Water quality	Bioenergy used to expand access to modern energy services	Energy diversity
Biological diversity in the landscape	Change in mortality and burden of disease attributable to indoor smoke	Infrastructure and logistics for distribution of bioenergy
Land use and land-use change related to bioenergy feedstock production	Incidence of occupational injury, illness and fatalities	Capacity and flexibility of use of bioenergy

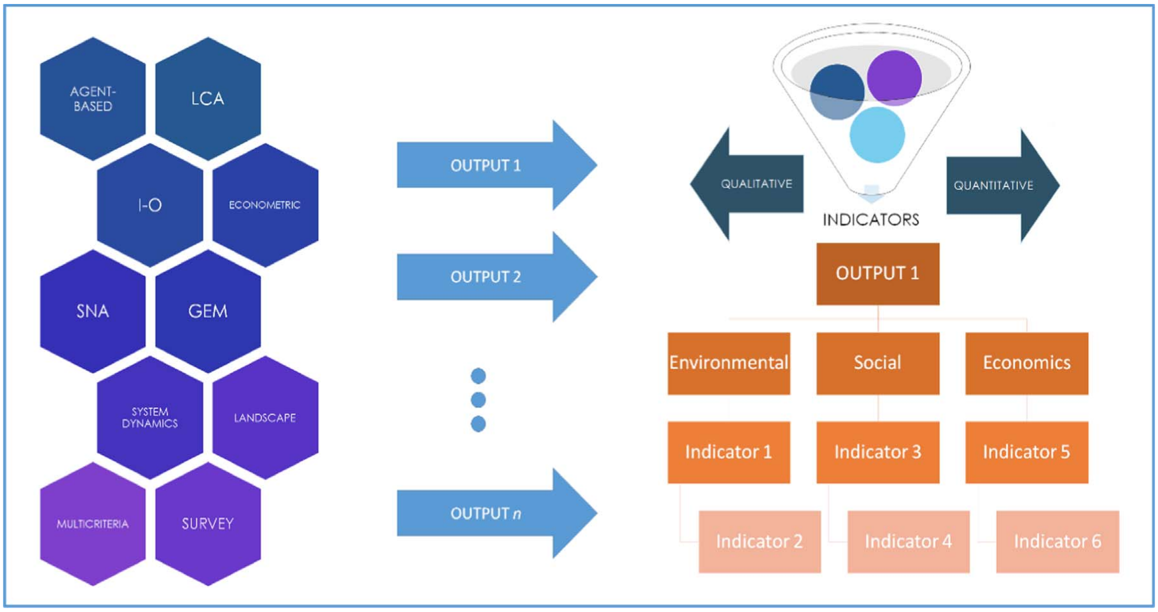

Fig. 4. Example of Applying Indicators from Methods output.
From authors.

2.5. Analysis of feasibility and acceptability

The key point for the conception and application of sustainable bioenergy projects is the analysis process, which includes understanding the indicators, models, and measures applied. Such analysis determines the feasibility of the project and serves as the turning point of the study. The results must be evaluated prior to the final decision of the policymaker.

Indeed, this perspective, commonly known in the literature as the acceptability (or desirability) problem, can directly mitigate all of the previous effort made in achieving the feasibility. Sometimes a generally positive condition for bioenergy development can be translated into a negative perception of relevant stakeholders and public opinion. In addressing this paradox, such we must first recognize two separate factors that are not automatically detected and can often be in disagreement: inherent context (IC) and perceived context (PC).

We consider IC as the overall objective in a fact-based environment in which bioenergy projects already exist or will exist. This context is defined by a series of quantifiable indicators classified into thematic categories such as economic, social, environmental, agricultural, technological, and legal factors. In the SIByl-LACAf framework, the previously discussed steps guide the policymaker in achieving feasibility. These aspects are part of a specific context following scientific procedures with indicators as main results. Without an external influence, this scenario translates the reality in the IC.

In contrast, we consider PC as a subjective environment in which highly diversified perceptions and opinions of bioenergy interact and affect the potential development of sustainable bioenergy systems. Unlike IC, PC is based entirely on public perception rather than fact. External forces are present and can directly influence the actors and the decisions. Indeed, the power of public perception should never be underestimated. It can often result in stronger arguments in favor or against bioenergy development compared with scientific facts that underpin the objective feasibility of bioenergy projects. Indeed, public perception is critical in determining the acceptability of a sustainable bioenergy project regardless of its feasibility.

Because public opinion and perception are so diverse and are often not based on scientific fact and evidence, these aspects are difficult to evaluate. This challenge is not limited to academic analysis, however. The private industry actors that implement bioenergy projects are affected to an even greater extent by the opportunities and threats presented by varied and volatile public perception on bioenergy-related issues.

This is precisely why Public Consultation and Communication (PC & C) [93] mechanisms are important steps in the implementation of any bioenergy project, as a systematic process that seeks the public's input on civil matters.

The basic rationale underlying PC & C is the right of the public to be informed and consulted and to express opinion on matters of relevance. Its main objective is to improve the efficiency, transparency, and public involvement in large-scale projects or laws and policies. This process usually involves public notification to publicize the matter under consideration, consultation including a dialectical, two-way flow of information and opinion exchange, and participation of interest groups in the drafting of policy or legislation. The PC & C process should lead to better decisions and can lead to improved relations between a developer and the public. Where PC & C processes have been implemented in sustainable bioenergy projects, the minutes and findings of the reports on such processes are a rich source of information that can be used to analyze and evaluate PC in the development of bioenergy.

The analytical framework used to evaluate all of the factors stemming from IC and PC is included in IA. This version is slightly adapted from a traditional SWOT analysis model [94–96] used in the structured planning of a project or business venture. Traditional SWOT analysis aims to identify the key internal and external factors deemed important for achieving an objective. Strengths and weaknesses are grouped as factors included in a business or organization, and opportunities and threats are grouped as external environmental factors of the business or organization. Strengths and opportunities are considered as helpful in the achievement of objectives, whereas weaknesses and threats are viewed as harmful.

The crucial difference between the traditional SWOT analysis model and SIByl-LACAf is that the latter substitutes the internal factors with IC. In the former method, the scientific fact-based characteristics that determine the practical feasibility of sustainable bioenergy projects are considered in the external environment with PC. That is, highly varied perception of sustainable bioenergy systems, real or imagined, is held by a variety of stakeholders.

Fig. 5 shows the structure of analysis in which the SIByl-LACAf framework can address the feasibility–acceptability problem. Step 5, analysis of feasibility, is considered on the basis of information

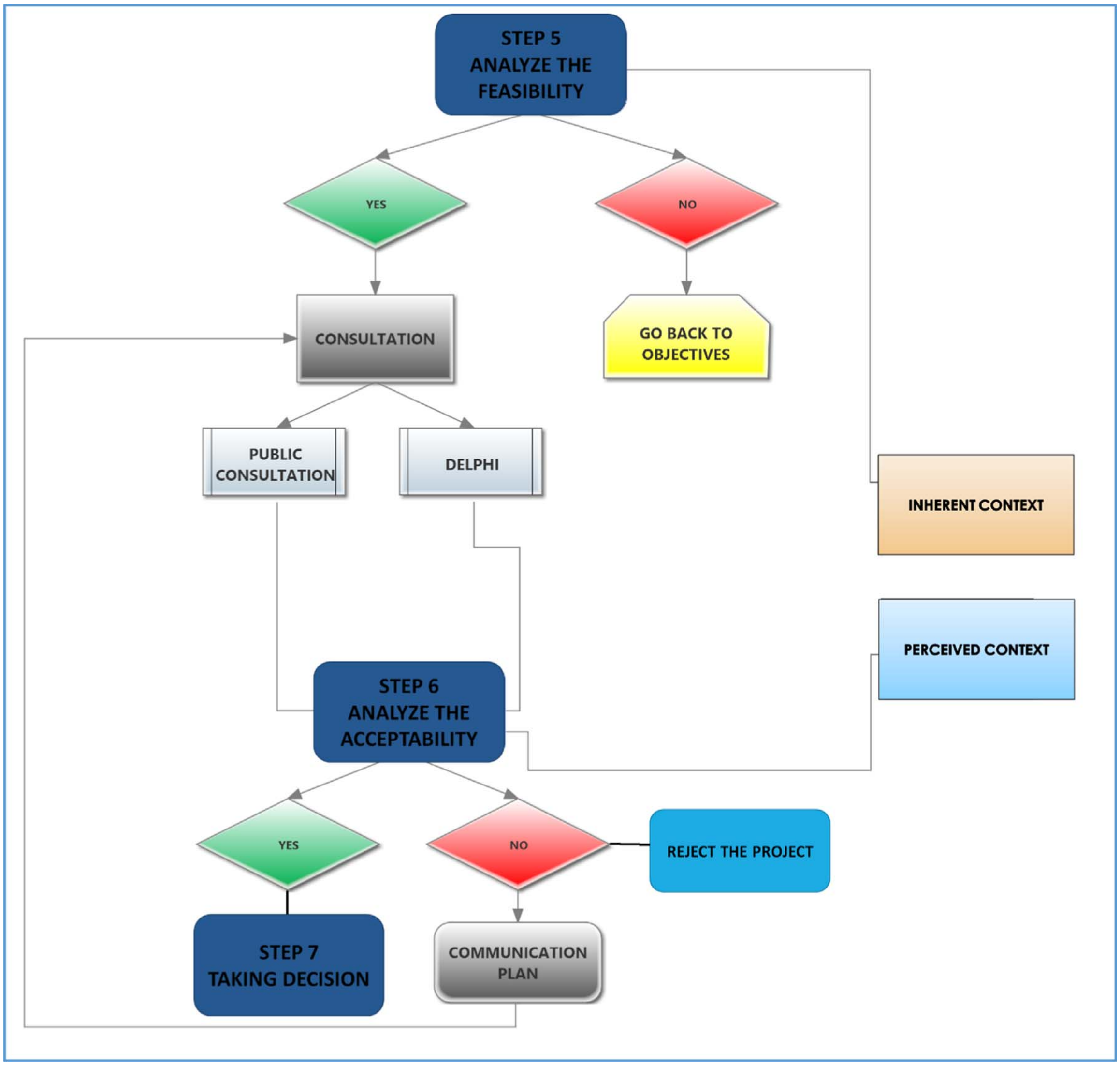

Fig. 5. The process feasibility and acceptability problem.
From authors.

determined from the previous steps. Here, the policymaker can determine whether a project is feasible in terms of previously reported information. If the consultant verifies a "no" as the answer, there is no reason to continue the analysis, the project does not present interest. In fact, a review of the objectives and reconsideration of the problem can be developed in such cases, depending on the context. However, if a "yes" answer is verified, the next step is consultation. In this step, the desirability of the project perceived by the community is addressed.

As previously mentioned, the public consultation is an important tool for understanding the perception of the actors. The Delphi method [97] is also suggested to verify the opinion of more specialized actors of the community. As a group, both procedures feed Step 6, analysis of the desirability, and a new question emerges: Is the sustainable bioenergy project acceptable and desired by the actors?

If the consultant verifies a "no" answer, differently from Step 5, there is no reason to review the objectives. Here, the communication plan [93] can be directly used to inform the community of the feasibility analysis results to avoid misunderstandings and incorrect preconceptions. However, we stress that this process is not intended to force the opinions in achieving a desirable result.

In Latin America, the Caribbean, and Africa, the particular countries under study, the acceptability (desirability) of sustainable bioenergy projects appears more frequently than expected in the literature. Obviously, after implementing the communication plan, returning to the consultation stage and reanalysis of Step 6 is suggested until a "yes" answer is obtained. After the positive answer is verified, we suggested advancing to Step 7: taking decision.

Next, we will discuss how the information obtained from the previous steps can be used to guarantee that the policymaker makes the final decision.

2.6. *Taking decision*

Step 7, taking decision, summarizes the process suggested by the SIByl-LACAf framework and helps the decision maker to achieve both feasibility and acceptability under a sustainable, integrated framework well suited for the selected countries and their peculiarities.

As previously mentioned, the SWOT matrix represents both IC and PC under the SIByl-LACAf structure of analysis. Here, we use this method to simplify the process of taking decision. There is no reason to construct a highly complex framework if the taking decision process is more complex than the entire information structure.

When the decision makers achieve Step 7, all of the procedures, information, indicators, and limitations are known but are not well structured. The SWOT matrix is used to translate the results into helpful and harmful categories to achieve the objectives. The decision maker has to consider the following blocks from previous information: i) strengths: IC; ii) weakness: IC; iii) opportunities: PC; and iv) threats: PC.

Obviously, comparing different projects that are both feasible and acceptable is easier if the strengths and opportunities outnumber the weakness and threats. In summary, our objective is to provide guidelines for decision makers by expertly answering four questions that are relevant to similar sustainable bioenergy projects in the future: 1) How can the strengths in the IC be used to take advantage of the opportunities presented in the PC? 2) How can the strengths in our IC be used to reduce the likelihood and impact of the threats present in the PC? 3) How can the weaknesses in the IC that translate into threats in the PC be overcome? 4) How can such weaknesses be addressed?

Educated and carefully evaluated answers to these questions can form the basis of guidelines and recommendations for policymakers and decision makers in future sustainable bioenergy projects with similar conditions and characteristics. Fig. 6 summarizes the conceptual framework of SIByl-LACAf.

3. How to implement the SIByl-LACAf

The previous sections showed how the theoretical structure of SIByl-LACAf can work under different country peculiarities and hypotheses. Initially, the complexity of this approach is not easily understood. In this scenario, the implementation process of SIByl-LACAf in a specific country includes numerous direct and indirect factors, which can result in complexity. The problem begins by defining the objectives. Once the scope of the study is defined, the process of data and information collection is important because it is directly related to the complexity of the analysis. The previous steps will be linked with the chosen framework of analysis, where the inherent complexity of information is addressed in an integrated approach. The output information of the models and methods applied must summarize the key indicators that satisfy both the investigator decision criteria and external sustainable guidelines from international agencies such as GBEP and IDB Scorecard. Finally, stakeholders such as a specific agent or policymaker must make a decision. At this point, the problem emerges. To exemplify how our approach can be implemented, as follows is designed an application to Mozambique, a country where several bioenergy projects have been proposed and presents good potential for implementing bioethanol projects.

Mozambique is located on the east coast of southern Africa at the Indian Ocean. Its total area is 801,590 km^2, of which 2% is inland water. The climate varies from tropical to subtropical, and about 78% of the territory is covered by trees or other woody vegetation. Productive forests including trees and bushes occupy at least 20 million ha, or 25% of the country's terrestrial surface [98].

About 54% of the population of Mozambique is below the poverty line despite the country's very high economic growth achieved during recent years. The total population is estimated to be about 20.4 million, with 63% living in rural areas. Subsistence agriculture employs about 80% of the labor force, which accounts for about 21.1% of the GDP. In rural areas, agriculture is the main activity for 95% of the households. The land and all natural resources belong to the state, which guarantees user rights to local communities and local and foreign investors [98].

The main sources of energy in the country are biomass, hydroelectric power (dams), solar power, liquid fossil fuel (gasoline and petroleum), and natural gas. The government has considered liquid biofuels in recent years as a method for decreasing the country's external energy dependence [98].

Batidzirai et al. [99] reported that Mozambique has an estimated capacity for producing up to 6.7 EJ/year of biomass with moderate introduction of agricultural technology. Such a project would meet basic sustainability criteria such as protection of forests and fulfillment of increasing food demands.

Of the 36 Mha of arable land, only 13.9% is in use. The possibility of using an additional 41.2 Mha of marginal land and the favorable climatic conditions are attractive prerequisites for biofuel production in Mozambique. The central part of the country is best suited for bioenergy production. However, the domestic market is relatively

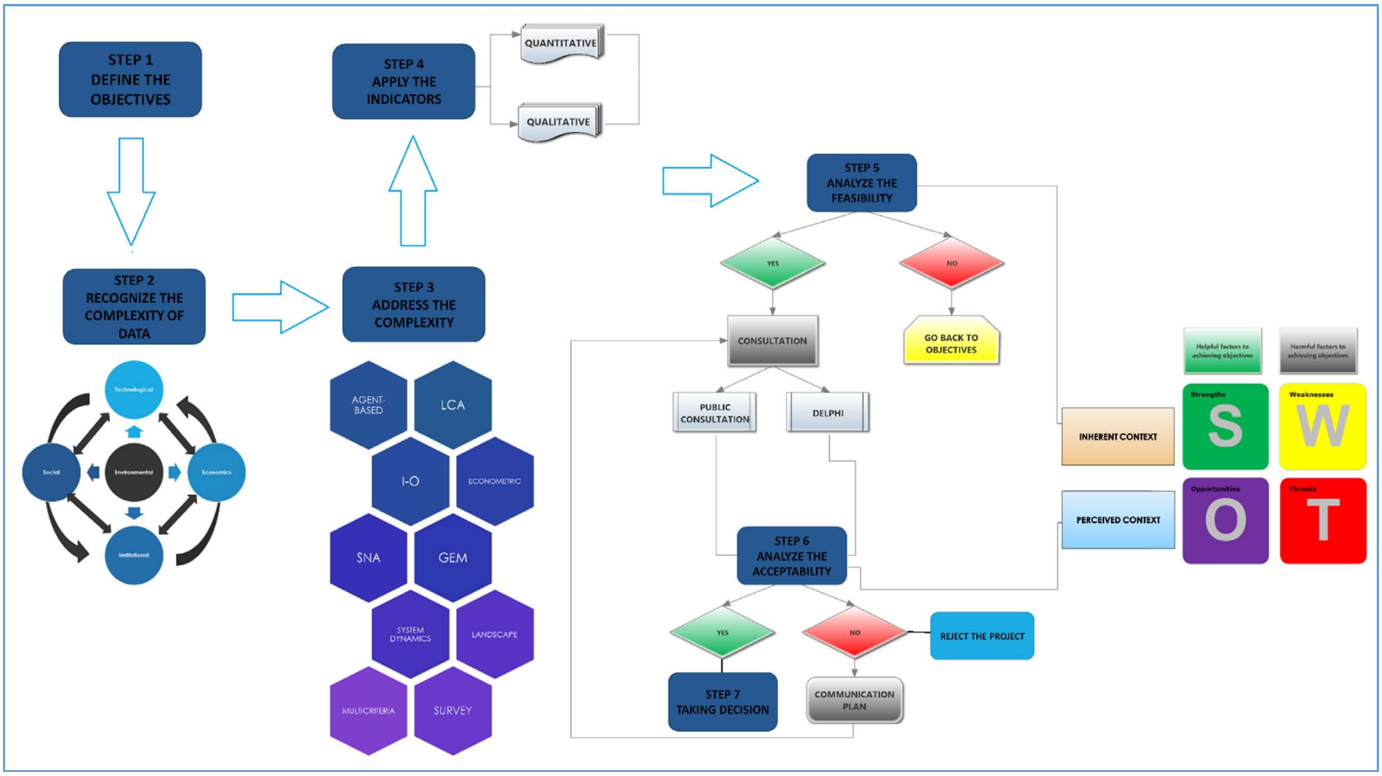

Fig. 6. SIByl-LACAf for Mozambique.
From authors.

Table 4
Databases and respective information for answering the objectives for Mozambique.

Database	Source	Description
Global Trade Analysis Project – GTAP 9.0	Purdue University	Source of a Social Account Matrix for Mozambique, Input–Output Matrix
FAOSTAT	FAO	Production, Trade, Emissions; Agriculture, Emissions; Land Use, Food Security, Agri-Environmental Indicators, Food Balances, Prices, Inputs, Population, Investment, Forestry, ASTI R & D Indicators
ISI Web of Science	Thomson Reuters	Scientific Publications
World DataBank	The World Bank	Population, Surface area, Population density, Poverty, GNI, Life expectancy at birth, Fertility rate, Forest area, Energy use, CO2 emissions, Electric power consumption, GDP at market price, Inflation, Agriculture value added, Industry value, Services value added, Exports-Imports and services, Gross capital formation, Revenue, Cash surplus, Tax revenue, Net migration and others
IEA	International Energy Agency	Population, GDP, GDP PPP, Energy Production, Net Imports, TPES, Electricity consumption, CO2 emissions, Coal, Electricity and Heat, Natural Gas, Oil, Renewables and Waste, Balances
WTO	World Trade Organization	Tariff, Agriculture, Antidumping, Balance of Payments, Import Licensing, Regional Trade Agreements, Rules of Origin, Safeguards, Sanitary and Phytosanitary, Technical barriers to trade, Trade-related investment measures
Millennium Development Goals Indicators	United Nations	i) Eradicate extreme poverty and hunger; ii) achieve universal primary education; iii) promote gender equality and empower women; iv) reduce child mortality; v) improve maternal health; vi) combat HIV/AIDS, malaria and other diseases; vii) ensure environmental sustainability; viii) develop a global partnership for development
UNCTADSTAT	UNCTAD	Total labor force and agriculture labor force, total and urban population, personal remittances, free commodity prices, information economy, creative economy, maritime transport, foreign direct investment, trade trends, trade structure by partner, trade indicators, market access

limited and potential market for export is located in the South, specifically in South Africa, which makes the bioenergy produced in Mozambique in the middle–short term less competitive [99].

Schut et al. [100] provided a detailed overview in which the agro–ecological conditions were combined with socioeconomic conditions in establishing the production of biofuel feedstocks. The results indicate that the socioeconomic conditions are crucial for the actual development of biofuel production in Mozambique.

Step 1. *Define the objectives.*

As previously discussed, the Mozambican agriculture has considerable potential owing to its vast reserves of land suitable for cultivation. Thus, the government hopes to take advantage of this quality by encouraging agriculture in view of economic development. The economic impact of agriculture development has social implications because most of the Mozambican population resides in rural areas.

Considering liquid fuel, bioethanol is recognized as the best current option for sustainable biofuel in tropical countries with good edaphoclimatic conditions for growing sugarcane. In the context, a hypothetical application for SIByl-LACAf approach could be adopted in Mozambique if investment is made in sustainable bioenergy plants for bioethanol production from sugarcane.

In this sense, we suggest the following specific objectives:

i. Define the selected areas from the edaphoclimatic conditions for growing sugarcane.
ii. Define the best scale of production.
iii. Verify whether the project is sustainable in terms of economic, social, and environmental factors.
iv. Build and evaluate macroeconomic scenarios and business cycles.
v. Evaluate the institutional environment and legal restrictions for implementing bioenergy projects.
vi. Verify the direct and indirect effects of project implementation on sectors.
vii. Verify whether the project is feasible and acceptable.
viii. Select the strengths, weakness, opportunities, and threats of the project.

Step 2. *Recognize the complexity of data.*

The complexity of data is a clear issue for the Mozambique case. Thus, when an expert uses the SIByl-LACAf framework, situations will be encountered in which the data are not exclusive and can be used in other cases. In fact, the data can be shared for more than one objective elected in Step 1 and are used in one or more models from Step 3.

In this step, the expert searches the main and secondary databases to obtain information about economics and social, environmental, technological, and legal factors among others. An interesting approach is exploring Mozambican agencies, government departments, and statistics bureaux to find reliable databases compiled by regular methods through time with certain frequency.

Such effort will be more complex in less-organized institutional environments. In some cases, the secondary database is insufficient, and primary data should be collected. A second problem emerges in such cases because data collection is highly expensive and can affect the analysis of the project.

It is important to consider that this step includes verification of the presence or absence of reliable data for the analysis and evaluation of the complexity in their collection; regular data are more easily obtained. The data should include economics and information on social, environmental, technological, and legal aspects. The methods of the next step are directly related to the quality of this information (Table 4).

Step 3. *Address the complexity.*

This step is derived directly from the objectives elected for the Mozambican case and from the disposable data from Step 2. More complex and complete framework has more disposable data and is less expensive in time and cost.

If secondary databases must be used, methods can be implemented to address complexity imposed by the objectives selected in Step 1.

This step is influenced by the expert applying the SIByl-LACAf framework because different but complementary methods or procedures must be considered when evaluating the feasibility.

The following methods and objectives are suggested:

i. LCA: Define the selected areas from the edaphoclimatic conditions for growing sugarcane and scale best suited for production.
ii. LCA, I–O analysis, and SNA: Verify whether the project is sustainable in terms of economic, social, and environmental factors.
iii. Econometric models such as time series and GEMs: Build and evaluate macroeconomic scenarios and business cycles.
iv. SNA and survey: Evaluate the institutional environment and legal restrictions in implementing bioenergy projects.
v. LCA, I–O analysis, and GEMs: Verify the direct and indirect effects among the sectors for project implementation.

Step 4. *Apply indicators.*

The output of previous step will be translated into quantitative and qualitative indicators. Step 4 is useful for aligning the indicators within

Table 5
Suggested indicators for Mozambique.

Model	Indicator	Understanding
LCA	Emissions, Recyclable Waste, Co-products, Water Usage, Landfilled Waste, Dumping Littering	Helps to understand if Mozambique has good edaphoclimatic conditions for producing bioethanol from sugarcane and what benefits can be introduced like reducing emissions, better water use, etc.
I-O	Production Multipliers - Direct, Indirect and Induced Effects, Employment Multipliers, Jobs, Sectoral Interdependence	The analysis of the I–O for Mozambique has the capacity to directly help the decision-maker in the feasibility step. Here the benefits can not only be evaluated in the corresponding economy sector, but also through sectors of the economy. This method is interesting for governments to identify special sectors or activities that can improve the creation of new jobs and improve yield in the industry.
SNA	Network indexes as centrality, density	The SNA approach can identify the main actors that Mozambique maintains a certain relationship to produce knowledge and identify potential ones. In the middle and long term, Mozambique will have to generate innovative business to improve the biofuel-based economy.
GEM	Scenarios, price change, GDP variation, inflation variation, gross capital formation variation, inter-sectoral relationship, exchange rate variation	In the same direction as I–O, the GEM method will be useful to generate scenarios to evaluate the impacts in the macroeconomic aggregates. It is also useful to assume some information from LCA, I-O and Econometric models, integrating the methods as proposed by SIByl-LACAf.
Survey	Qualitative and quantitative answers	Once there is scarcity of primary data in Mozambique, an important step will be to achieve information through surveys with the community. How big and extensive this application will be depends in how big/costly the project is.
Econometric	Trends, Growth, Variable Relationship, Co-integration, Cycles and Seasonality	The use of secondary data can be interesting to evaluate some directions and trends inside the existing economy of Mozambique. The econometric data can be useful to build some macroeconomic aggregates over the next years, such as GDP, production, exchange rate, that can directly affect the costs and perspectives of the project.

international standards and guidelines of IDB Scorecard, GBEP, and other programs.

In this phase, is important to verify the contribution of each indicator in answering specific questions arising from the economic, social, environmental, technological, and legal perspectives mentioned in Steps 1 and 2.

The key of this step is determining how to simplify the output information from the methods and models into easily interpreted information for the decision maker. This will be helpful in the feasibility analysis in Step 5 and for filling the required information of the SWOT matrix from Step 7 (Table 5).

Step 5. *Analyze the feasibility.*

All of the information translated in the indicators in previous steps will be helpful in analyzing the feasibility of the project. Obviously, the key is to verify whether the project is feasible.

In this situation, the policymaker will face the traditional evaluation problem of feasibility; however, the disposable information and indicators of previous steps are available. Once the parameters for considering the feasibility such as interest rate, period, investment value, sustainable standards, and comparable projects are, defined, the policymaker can make the decision. The use of additional methods is helpful in evaluating the feasibility of the project. However, in the framework of SIByl-LACAf, Step 3 offers some methods that can address both the indicators and feasibility such as the multi-criteria, system dynamics, or agent-based models. Once the multi-criteria are selected the for Mozambican case (Step 2) and applied in Step 3, the results used to evaluate the feasibility are derived directly from the model. This avoids the application of other models and simplifies the analysis.

Step 6. *Analyze the acceptability.*

Once the project is evaluated as feasible, it is beneficial to evaluate its acceptability. In this step, we suggest application of first Delphi panel with specialists and second public consultation of local community, especially the community directly affected by the project. The Delphi results can guide the application of the public consultation.

The Delphi process can be conducted by selecting the key stakeholders of the bioenergy sectors in Mozambique and policymakers, researchers, and government actors after constructing the questions that emerged from the previous steps.

The Public consultation approach can be useful for understanding how sustainable bioenergy projects affect the community in Mozambique: i) if there is a preconception that can mitigates the efforts of the project; ii) if there is misunderstanding of the real benefits and harm from bioenergy plants to the environment, including economic and social aspects; and iii) if there are political issues that can mitigate all of the efforts. Public communication is key in correcting the problems mentioned above, although correcting the political issues is quite difficult. In such cases, it suggested that the Public Communication and Consultation (PC & C) procedure applied until reaching acceptability or if is verified that these problems are the main threats from the project.

Step 7. *Take decision.*

The final decision for the Mozambique case is directly linked to the results of Steps 5 and 6. Thus, to attain both feasibility and acceptability information must be filled in about the IC and PC inside the SWOT matrix.

Finally, the elements from strengths, weaknesses, opportunities, and threats can be filled by the policymaker, and a specific SWOT matrix and be constructed. After comparing the different alternatives of a specific project, if the strengths and opportunities outnumber the weaknesses and threats, this project will be selected as deserving to be implemented.

4. Conclusions and policy implications

Effective indicators can help to identify and quantify the multivariate attributes of bioenergy options. However, we caution that in the process of developing and using criteria and indicators, the limitations of data and modeling deserve careful attention. Even exhaustive and comprehensive analytical frameworks that account for factors within all of these spheres have demonstrated limitations. This is evidenced by the fact that, even in cases in which all or most of the evaluated spheres indicate positive results and the potential for bioenergy development, such projects are frequently met with overwhelming resistance by a wide variety of relevant stakeholders and public opinion. In other words, while such projects are deemed objectively feasible, they are not subjectively acceptable.

After the construction of the previous steps for analysis, the stakeholder will face different questions with different developments. If the taking decision process will be used only for feasibility, there will be three scenarios: i) not feasible, in which the objectives are re-evaluated; ii) not feasible, and the project is denied; and iii) feasible.

However, as suggested, the stakeholder might want to understand how acceptable the project is and how to implement the project.

In this context, we suggest additional steps for achieving feasibility and acceptability under the SIByl-LACAf approach. A problem emerges because relevant stakeholders and public opinion can sometimes translate a generally positive condition for bioenergy development into negative perception. Thus, we must first recognize that there are two separate contexts at work here, which are not automatically causal and can often be at odds with each other. These contexts are identified IC and PC. We define the IC as the overall objective (fact-based) environment in which bioenergy projects already exist or will exist.

The analytical framework is constructed in a way to use the information of the feasibility taking decision process to feed the first line of the adapted SWOT matrix, the IC line. This line is important because it is used to identify the strengths and the weaknesses of the project. The second line of the SWOT matrix, PC, will elucidate the opportunities and threats of the project. This second step involves the use of PC & C re-structured for our purpose.

After the feasibility analysis, two different procedures are use in which a panel of experts is created following the Delphi method [97] and public consultation [93]. After use both procedures, another decision process emerges. If it is understood that there is no acceptability, the use of a communication plan is suggested [93] with a return to the consultation step or denying all the project. In the case of achieving acceptability, the information will feed the PC line of the SWOT matrix, which will bring information about the opportunities and threats of the project.

Finally, the policymaker will face a SWOT matrix that is deeply scientific or based on other terms of IA for bioenergy systems. This process will shed light on the taking decision process and will help in the final decision.

The SIByl-LACAf framework aims to contribute to the decision-taking process by organizing, integrating and processing properly information, and so developing a sound feasibility assessment of bioenergy systems, as well as introduce an acceptability evaluation in order to identify and correctly deal with the local communities perception, an actual issue in countries that can expand bioenergy production in the next years.

The application of the SIByl-LACAf approach for Mozambique was a preliminary suggestion of steps in a context where it is clearly required an Integrated Analysis and data are limitedly available. We expect that the framework will be applied and evaluated for researchers and policymakers that work with bioenergy and have to handle with the acceptability situation.

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