Research, Society and Development, v. 9, n. 11, e2099119794, 2020
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v9i11.9794

Analysis of methodologies used to assess bioethanol sustainability

Análise das metodologias utilizadas para avaliar a sustentabilidade do bioetanol

Análisis de las metodologías utilizadas para evaluar la sostenibilidad del bioetanol

Received: 10/30/2020 | Reviewed: 11/03/2020 | Accept: 11/07/2020 | Published: 11/11/2020

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Abstract

Considering the importance of the search for sustainability and the growing emphasis given to biofuels, promoted as a promising alternative energy, this study highlights the relevance of research that evaluates sustainability in the bioenergy sector, specifically bioethanol. The present work aims to analyze methodologies aimed at assessing the sustainability of bioethanol using a literature review and, based on this analysis, indicate the most suitable methodology. The most popular methodologies used to assess the sustainability of bioethanol were identified from the bibliographic survey and screened according to pre-established criteria of exclusion, based on keywords, and inclusion, regarding the pillars and biofuel addressed. First, it was found that the studies were conducted in different regional contexts and used different methodologies, which could provide both quantitative and qualitative results. After screening and selection, the evaluation methodologies adopted by each author were analyzed. This analysis made it possible to recognize the factors influencing the choice of methodology, where the suitability of a methodology to the particularities of each case was of great importance. Finally, considering the pre-defined criteria for assessing the

sustainability of bioethanol, this paper recommends the GBEP (Global Bioenergy Partnership) methodology as the most appropriate, especially since it was created specifically for the bioenergetic sector and has an accessible application protocol. Lastly, it was also noted that few publications evaluate the sustainability of bioethanol considering its entire three dimensions (social, environmental, and economic), emphasizing the importance of developing more studies with this approach.

Keywords: Bioethanol; Methodology; Sustainability; Indicators.

Resumo

Considerando a importância da busca pela sustentabilidade e a crescente ênfase dada aos biocombustíveis, promovidos como uma alternativa energética promissora, este estudo destaca a relevância de pesquisas que avaliem a sustentabilidade no setor de bioenergia, especificamente o bioetanol. O presente trabalho tem por objetivo analisar metodologias voltadas para a avaliação da sustentabilidade do bioetanol por meio de uma revisão da literatura e, com base nessa análise, indicar a metodologia mais adequada. As metodologias mais utilizadas para avaliar a sustentabilidade do bioetanol foram identificadas a partir do levantamento bibliográfico e triadas de acordo com critérios pré-estabelecidos de exclusão, a partir de palavras-chaves, e inclusão, quanto aos pilares e biocombustível abordados. A princípio, se verificou que os trabalhos foram desenvolvidos em diferentes contextos regionais e utilizando metodologias distintas, que podem fornecer tanto resultados quantitativos quanto qualitativos. Após triagem e seleção, foram analisadas as metodologias de avaliação adotadas por cada autor. Esta análise permitiu reconhecer os fatores que influenciam a escolha da metodologia, onde a adequação de uma metodologia às particularidades de cada caso foi de grande importância. Por fim, considerando os critérios pré-definidos para avaliação da sustentabilidade do bioetanol, este trabalho recomenda a metodologia GBEP (Global Bioenergy Partnership) como a mais adequada, principalmente por ter sido criada especificamente para o setor bioenergético e ter um protocolo de aplicação acessível. Posto isto, se percebeu que poucas publicações avaliam a sustentabilidade do bioetanol considerando todas as suas três dimensões (social, ambiental e econômica), enfatizando a importância do desenvolvimento de mais estudos com esta abordagem.

Palavras-chave: Bioetanol; Metodologia; Sustentabilidade; Indicadores.

Resumen

Considerando la importancia de la búsqueda de la sustentabilidad y el creciente énfasis dado a los biocombustibles, promocionados como una auspiciosa alternativa energética, este estudio resalta la relevancia de las investigaciones que evalúan la sustentabilidad en el sector bioenergético, específicamente del bioetanol. El presente trabajo tiene como objetivo analizar metodologías que evaluen la sustentabilidad de éste a través de una revisión de literatura y, con base en ello, indicar la más adecuada. Las más utilizadas fueron identificadas a partir de un resumen bibliográfico y se proyectaron acorde a criterios preestabelecidos de exclusión, basados en palabras clave, e inclusión, en cuanto a pilares y biocombustibles abordados. Así, se encontró que los estudios fueron desarrollados en distintos contextos regionales y que utilizaban diferentes metodologías, las cuáles proporcionaron resultados tanto cuantitativos como cualitativos. Después de la proyección y selección, se analizaron las metodologías de evaluación adoptadas por cada autor. Esto permitió reconocer los factores que influyen en la elección, donde resultó de gran importancia aplicar la más idónea a las particularidades de cada caso. Finalmente, considerando los criterios predefinidos para evaluar la sustentabilidad del bioetanol, este artículo recomienda la GBEP (Global Bioenergy Partnership) como la más apropiada, ya que fue creada específicamente para el sector bioenergético y tiene un protocolo de aplicación accesible. Sin embargo, también se señala que pocas publicaciones evalúan la sustentabilidad del bioetanol considerando sus tres dimensiones (social, ambiental y económica), destacando la importancia de desarrollar más estudios con este enfoque.

Palabras clave: Bioetanol; Metodología; Sostenibilidad; Indicadores.

1. Introduction

Society is organized based on the capitalist system of production, which stimulates consumption, the accumulation of wealth, and the intensive exploitation of natural resources, leading to environmental and social problems. In view of this, we are faced with the challenge of seeking alternatives to reduce the continuous disposal and intense exploitation of natural resources – especially non-renewable ones – and of achieving sustainability (Maia & Pires, 2011). However, according to Ciegis, Ramanauskiene, & Martinkus (2009), overcoming these problems is complex, since solutions must balance economic, social, and environmental considerations, considered as the three pillars of sustainability (Parada, Osseweijer, & Duque, 2017).

With respect to this concept, it should be clarified that there is as yet no consensus or

standard methodology to assess sustainability in the literature. Since this environmental issue became a global issue, the tools used for this purpose have consisted mostly of environmental assessment or the concomitant assessment of two of these aspects, with socio-environmental and socio-economic assessments being those most often considered. It is supposed that this occurs due to the fact that each process / product, object of evaluation, has intrinsic characteristics, while the appropriate selection of indicators and / or the obtaining of essential information make the application of the three pillars difficult. In this context, the importance of developing more studies that evaluate the sustainability of products and processes from the perspective of the three pillars is emphasized, because such evaluations can facilitate decision making and the design of more sustainable alternatives and policies by industry, government, and researchers.

Moving towards the search for sustainability, biofuels have been gaining prominence in the last decades (Pezzo & Amaral, 2007). In recent years, policies have been developed to encourage their production and consumption, in the quest to reduce the use of fossil fuels, as they present themselves as a renewable and safe energy source (Morais, Pascoal, Rocha, & Martins, 2017). The term biofuel denotes liquid or gaseous fuels that are produced from biomass, bioethanol being an example of these (Ferreira, 2015). In the context of sustainability and reducing the use of non-renewable sources, lignocellulosic biomass, being a material rich in carbon, is an excellent alternative (Čuček, Martín, Grossmann, & Kravanja, 2014), comprising, in general terms, hemicellulose (20 – 35%), lignin (10 – 25%), and cellulose (35 – 50%) (Leite & Leal, 2007).

Brazil and the United States of America are the two largest producers of this biofuel globally (RFA – Renewable Fuels Association, 2017), producing bioethanol mainly from sugar cane and corn, respectively. Bioethanol originating from raw materials composed of saccharine and starch, also present in food products, is called first generation bioethanol. However, the production of second-generation bioethanol (2G), using residual biomass as raw material, is also on the rise (Carvalho, 2013) since, in addition to reducing the emission of greenhouse gases and dependence on fossil fuels, it presents itself as an alternative for the use of wastes that would otherwise be discarded or disposed of in the environment. Industrial waste, agricultural waste, and even solid urban waste can be used for this purpose (Rodrigues, 2011), resulting in a strategy that meets the requirements of the Circular Economy and appears to be sustainable.

The importance of developing studies that evaluate the sustainability of products and / or processes based on the three pillars of sustainability, and the contribution of 2G as an

energetic and environmentally friendly alternative, is evident. This work proposes to analyze the methodologies used to assess the sustainability of bioethanol obtained from a review of the literature, as well as, based on this analysis, recommending the most suitable methodology for this purpose.

2. Methodology

This study follows the exploratory qualitative research in order to investigate the use of methods in bioethanol sustainability assessment. It has been identified the main methodologies for assessing sustainability using a literature review as a resource. This approach is based on the Padilla-Rivera, Paredes & Güereca (2019), that summarized and analyzed the current research on the sustainability assessment of bioenergy production/use.

The research was developed using the CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) journals portal and using the following keywords: sustainability, assessment, bioethanol. Then, in order to further refine the search, the search engine “not” and the keyword “LCA” were added as exclusion criteria to the Initial Search, thus eliminating the works that possibly discussed only the Life Cycle Assessment (LCA) of bioethanol.

A screening stage was carried out on the publications found, seeking to select approaches that would meet the research objective: studies that evaluated the sustainability of bioethanol, taking into consideration all three dimensions. In addition, selection criteria were applied to papers, in which were excluded: studies that dealt with the economic, environmental, and / or socioeconomic aspects of biomass in isolation; studies that did not deal with bioethanol fuel; articles that dealt solely with the production of biofuels or biomass energy issues, so not addressing the methodologies for assessing sustainability. As a result of these exclusions, studies were limited to those that evaluated the sustainability of bioethanol at any stage of its production, even when another liquid biofuel was involved in parallel.

After the screening stage, data related to the methodologies recognized in each study were analyzed, seeking to identify which methods were used to evaluate each of the three dimensions, the factors that directly influenced the methodological choice, as well as any possible existing gaps. Thus, having identified and analyzed the methodologies related to the theme, the following criteria were considered in order to recommend the most appropriate: i) international perception of the methodology; ii) possibility of adapting the methodology to the product / process in question; iii) feasibility and practicality of implementation (regarding the degree of detail / instructions for application and the requirement for software / computational

resources).

3. Results and Discussion

Table 1 brings together the studies of bioethanol sustainability assessment that were selected. The studies are presented in chronological order, from 1996 to 2019, identifying the biomass used to produce bioethanol and the methodology used to carry out the sustainability assessment.

Table 1. Selected studies assessing bioethanol sustainability.

Year	Biomass	Methodology employed	Reference
1996	Sugar cane and grape	Emergy analysis.	(Bastianoni & Marchettini, 1996)(Bastianoni & Marchettini, 1996)
2008	Sugar cane	Multicriteria analysis (MCA)	(Smeets et al., 2008)
2008	Wheat	Energy and emergy analysis.	(Dong, Ulgiati, Yan, Zhang, & Gao, 2008)
2009	Unspecified lignocellulosic biomass	Sustainability metrics defined by the Institution of Chemical Engineers (IChemE)	(Morales, Terra, Gernaey, Woodley, & Gani, 2009)
2009	Wheat grains and / or straw	Emergency assessment.	(Coppola, Bastianoni, & Ostergard, 2009)
2011	Cassava	Emerging assessment from indicators.	(Yang, Chen, Yan, & Wang, 2011)
2011	Sugar cane	Exergy analysis.	(Ojeda, Sánchez, & Kafarov, 2011)
2011	Corn straw	Energy, exergy, and emergy analysis with the application of indicators.	(Liao, Heijungs, & Huppes, 2011)
2011	Sugar cane, potatoes, sugar beet, cereals, and wood	Multicriteria indicators.	(Nicollier, Blanc, & Erkman, 2011)
2011	Sugar cane	Analysis based on international sustainability criteria.	(Walter et al., 2011)
2012	Rice	Emergy analysis based on indicators.	(Liu, Lin, & Sagisaka, 2012)
2013	Sugar beet, corn, sugar cane, sweet sorghum	Multiple criteria approach for combining quantitative and qualitative proxy indicators.	(Posada et al., 2013)

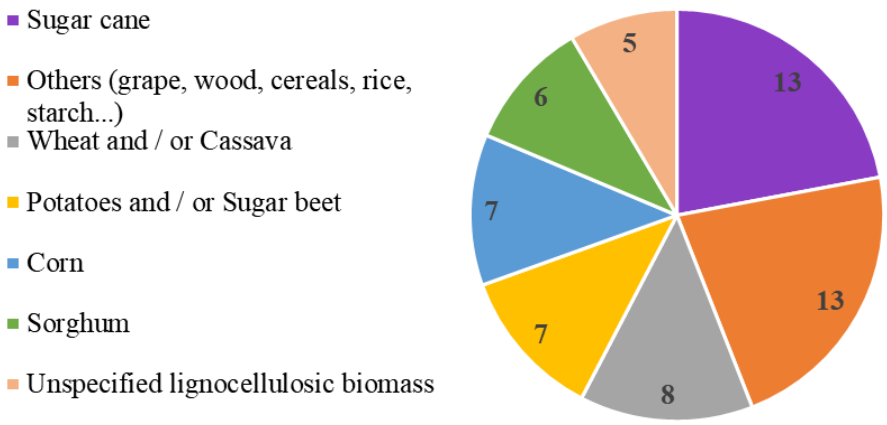
2013	Lignocellulosic materials	Sustainability indicators focused on the Process Design for Sustainability methodology (PDfS).	(Scott et al., 2013).
2013	Sugar cane	Preparation of a questionnaire with questions related to current sustainability requirements, based on the European Renewable Energy Directive and the Environmental Protocol of the State of Minas Gerais.	(Viana & Perez, 2013)
2014	Wood chips, commercial wood, sugar cane, corn kernels, sorghum, sweet sorghum, sunflower, African palm oil, and jatropha	Multi objective optimization.	(Aguilar, Campos, Ortega, González, & Halwagi, 2014)
2015	Lignocellulosic materials	Multiple criteria approach for generating a single sustainability index.	(Cheali, Posada, Gernaey, & Sin, 2015)
2015	Wheat, corn, and cassava	Combination of Life Cycle Sustainability Assessment (LCSA), Fuzzy Theory Multicriteria decision-making methodology (MCDM), Analytical Hierarchy Process (AHP) and VIKOR (means Multicriteria Optimization and Compromise Solution, in english) methods for assessing sustainability and determining the most sustainable scenario, considering the preferences of stakeholders / decision makers.	(Ren, Manzardo, Mazzi, Zuliani, & Scipioni, 2015)
2015	Sweet sorghum, sugar beet, corn, barley, potatoes, and wheat	MCA along with PROMETHEE II (Preference Ranking Organization Method for Enrichment Evaluations)	(Fokaides, Tofas, Polycarpou, & Kylili, 2015)
2016	Sweet sorghum, sugar beet, corn, barley, potatoes and wheat	MCA using the PROMETHEE II method.	(Kylili, Christoforou, Fokaides, & Polycarpou, 2016)
2016	Corn and wood	Optimization of multi-objective function.	(Miret, Chazara, Montastruc, Negny, & Domenech, 2016)
2017	Starch and sugar based raw material	Diffuse and hesitant multicriteria decision-making structure.	(Khishtandar, Zandieh, & Dorri, 2017)
2017	Sugar cane	Multicriteria method based on sustainability indicators.	(Gnansounou, Alves, Pachón, & Vaskan, 2017)
2017	Sugar cane and sorghum	Sustainability index integrated by indicators.	(García, Manzini, & Islas, 2017)
2017	Sugar, starch, and lignocellulosic waste	Analysis of various criteria in the context of the European Renewable Energy Directive, with sustainability	(Dammer et al., 2017)

		classification based on a traffic light system.	
2018	Sugar cane	Comparison of Environmental Impact Assessment studies and analysis of Bonsucro Certification, through the relationship between the analytical / conceptual framework of the two instruments based on indicators.	(Sozinho, Gallardo, Duarte, Ramos, & Ruiz, 2018)
2018	Sugar cane	Indicators proposed by the Global Bioenergy Partnership (GBEP).	(Violante, 2018)
2019	Cassava and sugar cane molasses	Computable General Equilibrium (CGE) models applied to five different simulation scenarios with application of indicators.	(Kaenchan, Puttanapong, Bowonthumrongchai, Limskul, & Gheewala, 2019)
2019	Cultivated crops	Multicriteria support for decision making conducted by the PROMETHEE I and II methods.	(Schröder, Lauven, Beyer, Lerche, & Geldermann, 2019)

Source: Produced by authors (2020).

It is notable that the first publication is dated 1996, this being, therefore, the oldest publication on the theme found using these search criteria. In addition, it is possible to observe that publication has become more intensive since 2008, becoming annual since 2011, which confirms the growing interest in sustainability and biofuels in the last decade. The publications presented were developed in different regional contexts and used different types of biomass for the production of bioethanol, as shows Figure 1. This figure presents all main biomasses used to obtain bioethanol according to the number of studies mentioned in Table 1.

Figure 1. Number of studies, by biomass, for bioethanol production.



Source: Produced by authors (2020).

This discussion is based on an analysis of publications that assessed the sustainability of the bioethanol production process taking into account the three pillars of sustainability, as well as the information present in Table 1, which presents a compilation of the studies found through bibliographic review.

In the context of the dimensions of sustainability, it was observed that LCA is a widely used tool that can be used for the evaluation of environmental variables. However, this observation then led to the realization that many studies evaluate the sustainability of bioenergy (including bioethanol) using LCA alone. Despite the consistent results obtained for the environmental aspect of sustainability when using this methodology, the need to obtain information regarding the economic and social aspects is highlighted, in order to guarantee the sustainability triad. Thus, it can be concluded that, although LCA provides a complete environmental overview of the target process / product, for sustainability to be ensured, it is still necessary to use a methodology that considers the other two aspects (social and economic), for otherwise it would be a purely environmental analysis. Another point noted was that the environmental aspect of sustainability is the one that receives the most attention in most studies and, not by chance, sustainability is usually associated only with the environmental character of the system.

Regarding the social aspect of sustainability, it was observed that this is given the least emphasis. It is notable that, in many cases, analysis of the social viewpoint is embedded in an economic (socio-economic) or environmental (socio-environmental) analysis, or is not even considered. Environmental variables were considered in all 28 studies analyzed, thus it was found that the most mentioned criteria are concerns regarding chronic and acute toxicity related to the production of biofuel, as well as regional development and job creation, the latter being the most often repeated indicator.

The economic aspect of sustainability was the second most cited in the studies, in comparison to the other parameters. Analysis of this aspect revealed that economic viability is considered to be the main and common indicator. In sequence, the issue of biofuel yield, process cost, global availability of raw material, production yield, micro and macroeconomic sustainability, and potential energy generation were also identified as issues.

That said, it was observed that most of the studies stated that providing aid to decision making was a general objective, be it to define the most sustainable means of generating biofuel, to determine the best crop to be cultivated in the country aiming to produce it, to establish which crop produces the most sustainable bioethanol, to compare biorefineries, or to indicate the best way to encourage the development of bioethanol in a given country. This

demonstrates the contribution that employing sustainability assessment methodologies can make to deciding on an action plan to be developed (in biofuels market) according to the proposal's objective. It was also noted that the choice of sustainability assessment methodology is determined by the objective of the assessment, and does not depend on the type of biomass in question. Regarding the criteria / indicators used, it was observed that they vary according to the interests and particularities of each case, being then selected to meet the purpose of each study – although, as mentioned above, some indicators are common among studies, even when there is a methodological protocol. However, regarding the methodologies applied in the studies, it was observed that, in the majority, they employed methods that provide quantitative results, that is, the indicators were normalized and, sometimes, ranked. However, quantitative methodologies are adopted when associated with computational resources or software routines. Furthermore, part of the studies had the common objective of helping decision making, by pointing out the most sustainable route to bioethanol production.

Therefore, considering the situation explained above, and the criteria established in the Methodology section, the most appropriate approach to evaluating the use of bioethanol is that developed by the Global Bioenergy Partnership (GBEP), an internationally renowned methodology which has been developed, above all, to assess the sustainability of the bioenergy sector. This recommendation is also based on its application protocol, which has 24 indicators at its core that incorporate the triad of the environment, economy, and society. It should be noted that the series of indicators proposed by GBEP encompasses the main indicators identified during the process of bibliographic review and the criation of Table 1.

As for the feasibility and practicality of employing the suggested methodology, in addition to proposing the indicators to be used, GBEP (2011) must also provide material to aid implementation and must not demand computational resources / software for verification of the result / sustainability index, since it is a methodology that performs qualitative assessment based on quantitative data.

From the above, it is apparent that it is essential to have enough information to allow the use of evaluation methodologies, where scientific articles, dissertations, theses, government agencies and technical information provided by industries / manufacturers are presented as potential sources of data collection.

4. Final Considerations

Of the total of articles generated from the literature survey stage, it was clear that only

a small number of studies (28) address the assessment of biofuel using the sustainability triad. This question shows that, despite the growing concern related to social responsibility and sustainable development, few productions analyze the sustainability of bioethanol from a holistic point of view, indeed most studies do so while considering only one or two pillars: environmental, economic, environmental / economic, or social / economic.

The studies identified were developed and proposed in different regional contexts and used to evaluate the production of bioethanol from different raw materials, which shows that evaluation methodologies can satisfy a range of motivations, as long as adjustments are made respecting the particularities of each case.

Finally, the methodology proposed by GBEP was judged to be the most promising for assessing the sustainability of bioethanol, especially when considering the fact that it is a methodology proposed specifically for the bioenergy sector.

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