Ecological Indicators 60 (2016) 84–107

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Biodiesel-TBL+: A new hierarchical sustainability assessment framework of PC&I for biodiesel production – Part I

S. Bautista[a,b,c,*], P. Narvaez[a], M. Camargo[b], O. Chery[b], L. Morel[b]

[a] *Grupo de Procesos Químicos y Bioquímicos, Department of Chemical and Environmental Engineering, Universidad Nacional de Colombia, Cra 30 45-03, Bogotá, Colombia*
[b] *ERPI (Equipe de Recherche des Processus Innovatifs), Nancy, France*
[c] *Grupo de Investigación en Agua y Desarrollo Sostenible, Department of Environmental Engineering, Universidad Central, Bogotá, Colombia*

ARTICLE INFO

Article history:
Received 25 March 2015
Received in revised form 11 June 2015
Accepted 16 June 2015

Keywords:
Biodiesel
Principles and criteria
Framework
Sustainability

ABSTRACT

Sustainability assessment of biodiesel production is a topic of increasing importance due to the interest of governments to define sovereignty strategies and diversification of their energy matrix, and to set up the impact of biofuels production. In this context, this work aims to propose a hierarchical structure of sustainability assessment that integrates dimensions of sustainable development with principles, criteria and indicators (PC&I). The method employed to define the hierarchical structure was a comprehensive literature review, based on information search strategy and classification. About 400 documents were reviewed and 103 documents were ultimately selected, including laws, policy documents, certificates, directives and other normative documents and papers published in peer-reviewed journals. The first result of the analysis was the need to strengthen identification of the sustainable development assessment, adding the political and technological dimensions to the three traditional dimensions, social, economic and environmental, studied in this kind of evaluation. The second result was the proposal of a hierarchical framework for the sustainability assessment of biodiesel production, organized in four levels: the first level comprises the five dimensions associated with sustainable development evaluation, the second includes 13 principles, the third contains 40 criteria and the fourth level corresponds to a set of indicators that describes each criterion. Outcomes of this work provide a foundation for further discussion of sustainability assessments for biodiesel production and its potential application in specific contexts.

1. Introduction

Global implications associated with the use of fossil fuels, such as variation in fuel prices, the future limitation of their offer and governments' concerns about energy security and sovereignty, encourage the development of alternative renewable energy sources. Such is the case with biomass such as feedstock to produce bioenergy, biofuels and bio-based products. Similarly, the growing demand for energy and the efforts of industrialized countries to reduce their carbon emissions, especially in the transport sector, promote the production of renewable biofuels (Gnansounou, 2011).

Nowadays, one of the most commonly used biofuel is biodiesel. Initially, it was defined as a mixture of mono-alkyl esters of fatty acids obtained from vegetable oils and fats (ASTM D6751, 2011). However, regarding the new developments and needs of the biofuel sector, its definition has evolved to include other types of biodiesel such as advanced biodiesel and biomass-based diesel (EPA, 2010). These new definitions include the former biodiesel (mono-alkyl esters), as well as non-ester renewable diesel (covering cellulosic diesel), the composition of which is similar to petroleum-derived diesel, and which are obtained from biomass, including vegetable oils, fats and cellulosic biomass (EPA, 2010). Despite the previous fact, most common biodiesel produced industrially is a mixture of mono-alkyl esters of fatty acids (FAME), obtained by methanolysis of oils extracted from rapeseed, soybeans and oil palm fruit.

Most industrial biodiesel production is performed by a conventional process, which uses a homogeneous alkaline catalyst, usually sodium or potassium methoxides, and in which are implemented purification steps with water to extract the catalyst, soaps, glycerol

* Corresponding author at: ERPI (Equipe de Recherche des Processus Innovatifs), Nancy, France. Tel.: +33 0383193239.
E-mail addresses: sancbautistar@unal.edu.co, sbautistar2@ucentral.edu.co (S. Bautista), pcnarvaezr@unal.edu.co (P. Narvaez), mauricio.camargo@univ-lorraine.fr (M. Camargo).

http://dx.doi.org/10.1016/j.ecolind.2015.06.020
1470-160X/

and other undesirable compounds (wet process) remaining in the biodiesel rich stream obtained after the transesterification and settling stages. Renewable non-ester biodiesel can be produced from vegetable oils by pyrogenolysis or hydrotreating, although industrial production is not yet fully developed. However, there is no doubt that renewable non-ester biodiesel will play a leading role in the future of biofuels (Pavlivna, 2012).

The main arguments for promoting biofuels were their potential positive effects on environmental, economic and social dimensions because they would help humankind to reduce the negative environmental consequences of burning fossil fuels and to extend non-renewable resource availability while a sustainable feedstock for energy and chemical products is found (Hill et al., 2006). In addition, job creation, especially in rural areas of developing countries, would allow governments to implement policies to reduce poverty and inequality. However, the negative effects of biofuel production on the dimensions previously mentioned gradually changed the perception of this bioenergy and opened debate about its sustainability. Some of the negative effects include alteration of ecosystems, degradation and loss of soil and water, changes in tenure and land use, impact on food security, the negative balance of greenhouse gases in the life cycle of biofuels, and the economic viability of their production (Hill et al., 2006; Gnansounou, 2011; Janssen and Rutz, 2011).

Likewise, in the debate on the sustainability of biodiesel production, studies show conflicting results on the same topic. For example, while Directive 28/2009 of the European Union (EC and EP, 2009) reports information savings in greenhouse gas GHG of biodiesel obtained from rapeseed, soybean and palm oils of 45%, 40% and 36%, respectively, in comparison to the fossil fuel replaced, other studies claimed that global GHG emissions increased due to changes in land use. This is because farmers react to the increase in the price of vegetable oils converting forests, peat-lands, savannahs or grasslands into further farmland to obtain the raw materials for biofuels. At the same time, other farmers plant traditional crops which were replaced by raw materials for biofuel crops (Fargione et al., 2008; Searchinger et al., 2008).

Another example of conflicting results in the study on the impact of biodiesel production is to compare the conclusions given by Hill et al. (2006) and Frondel and Peters (2007). Hill et al. (2006), who analyzed the life cycle of biodiesel from soybean oil, reported that it produces about 93% more energy than needed to be obtained, as well as reducing greenhouse gases by 41% compared to diesel it replaces; also that it reduces several pollutants and has minimal impact on human health and the environment through the release of N, P and pesticides. Frondel and Peters (2007) stated that the utilization of biodiesel instead of conventional diesel contributes less than 100% of the fossil energy contained in conventional diesel. Additionally, they reported the negative effects on the environment during the biomass production stage (consumption of natural resources, increased soil acidification and pollution of surface waters due to the dumping of pesticides) and burning (increased NOx emissions).

Otherwise, despite the social benefits associated with job creation and improvements in education, health, income and housing of the population closer to the lands where biomass is grown, negative effects on food security and food prices, land use and tenure, violence, forced displacement and low job quality should also be considered (Phalan, 2009). It was also observed that, in situations where the biodiesel production is no longer economically viable, or with lower short-term returns (Hoon and Gan, 2010), governments must set up policies related to tax exemptions and pricing schemes (Craven, 2011). An artificial market which is too reliant on support measures such as government policies, subsidies and tax exemptions would collapse once these policies and incentives are withdrawn (Hoon and Gan, 2010).

Regarding the previously mentioned context, emerging studies have implemented different methodologies to establish probable future scenarios where sustainable production of biodiesel could be achieved. Relevant examples include studies in South Africa (Musango et al., 2011; Musango et al., 2012; Brent et al., 2013), Brazil (Milazzo et al., 2013), Chile (Iriarte et al., 2012), Latin American (Janssen and Rutz, 2011; CEPAL, 2011), China (Wang et al., 2011), India (Schaldach et al., 2011), Europe (Ulgiati et al., 2008; Malça and Freire, 2011) and Malaysia (Lim and Teong, 2010), among others. Although results obtained answered some of the questions related to sustainable biofuel production, they generated additional enquiries that should be resolved. For example, there is no consensus on the dimensions to be considered to define in a comprehensive manner the conditions defining sustainable production. Nor on specific metrics that would make it possible to measure the level of sustainability.

In the search for methods and tools to solve such issues, organizations and researchers have proposed strategies such as certification schemes or voluntary standards to ensure sustainability in an international market for bioenergy (Delzeit and Holm-Müller, 2009), regulatory frameworks associated with directives, standards and laws applicable to a particular country, and frameworks or schemes related to control standards and indicators (Scarlat and Dallemand, 2011). Examples of these include system certifications such as the Roundtable on Sustainable Palm Oil, the Roundtable on Responsible Soy, carbon certificates, CEN (European Committee for Standardization), standards for sustainable biomass production in bioenergy applications, and the Roundtable for Sustainable Biofuels, among many others (FAO and BEFSCI, 2011). The most recognized regulatory frameworks are the renewable energy directive of the European Parliament, the Renewable Fuel Standard in the United States, and the mandate of renewable biomass in Germany. Among the control and command schemes for sustainable biofuels, those established by the Inter-American Development Bank and the control scheme of the World Bank and World Wide Fund for Nature (WWF) deserve to be mentioned (Scarlat and Dallemand, 2011).

The certification and assessment strategies mentioned above have in common that they consider the impact of biofuel production on sustainable development dimensions (traditionally the social, environmental and economic dimensions), but with these strategies it is difficult to show whether there are interdependencies or to measure the influence between impacts. Additionally, the influence of technological changes (e.g. changes in raw materials or production routes), political changes (international agreements, local regulatory standards); life quality of communities, or economic variations such as changes in oil prices, food prices or cropland price issues are weakly considered by the strategies of certification and evaluation.

Moreover, there are methodological difficulties to effectively manage an evaluation structure and decision-making against the negative impacts generated in the biodiesel supply chain. This is due to five aspects. The first is the multistage process of the biodiesel supply chain, such as the production of raw materials (mainly biomass), oil extraction, and biodiesel transformation, storage, transportation and marketing. The second aspect is the complex relationships between the geographical and cultural contexts with the stages of the biodiesel supply chain. The third refers to the various actors involved in the production chain (Awudu and Zhang, 2012). The fourth aspect is associated with achieving a set of dimensions sufficiently holistic and comprehensive of sustainable development that embraces the relationships between social, economic, political, technological and environmental variables. Finally, the fifth aspect is the difficulty of establishing an evaluation framework to assess these dimensions.

Considering the need for a sustainability assessment framework that addresses the methodological problems mentioned above, the