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BIODIESEL-TBL+: A NEW HIERARCHICAL SUSTAINABILITY ASSESSMENT FRAMEWORK OF PC&I FOR BIODIESEL PRODUCTION

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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.

Key words: Biodiesel, principles and criteria, framework, sustainability

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 (Edgard 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 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 pyrolysis 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 (C. E. 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 & Peters (2007). Hill et al (2006), who analysed 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 NO_x 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 (Brent and Musango 2013; Musango et al. 2011, 2012), Brazil (Milazzo et al. 2013), Chile (Iriarte, Rieradevall, and Gabarrell 2012), Latin American (CEPAL 2011; Janssen and Rutz 2011), China (Wang, Calderon, and Lu 2011), India (Schaldach, Priess, and Alcamo 2011), Europe (Malça and Freire 2011; Ulgiati, Russi, and Raugei 2008) 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 objective of this research is to propose a hierarchical framework of sustainability that integrates the dimensions of sustainable development principles, criteria and indicators of sustainability. The method to define the assessment framework is based on a comprehensive state of the art, resulting in a selection and analysis of 103 documents, including laws, directives and other normative documents, policy documents, certificates and papers published in peer-reviewed journals.

The remainder of this paper is structured as follows. The first section, an insight from previous literature, was developed in order to identify relevant documents for this work and to justify the research questions. Then, the second section presents the methods used to establish the state of the art, descriptive document analysis and selection. The third section shows a descriptive analysis of the results and the selected documents and their classification. Additionally, sustainability assessment dimensions are taken into account in this work, as well as the frameworks previously used for sustainability assessment. The fourth section presents the new sustainability assessment framework for biodiesel. In the fifth section, the application of the new assessment framework on biodiesel production is proposed. Finally, section six presents the discussion regarding topics such as applicability of a sustainability assessment framework, the adequacy of principles and criteria for sustainability assessment, and identification of principles and criteria research needs.

1. Insight from previous literature

The purpose of this background on previous literature reviews is to help relevant documents enable us to underline the main research questions of the present study. Table 1 summarizes 16 recent documents regarding research focus, author, number of papers reviewed, time, source and sustainable dimensions considered (social-S, economic-Ec, environmental-En, political-P and technological-T). These studies are classified through a typology reflecting the research focus, such as: biodiesel supply chain studies, quantitative approaches (models

and metrics), sustainability frameworks of criteria and indicators for bioenergy and biofuels, and sustainability initiatives (regulatory frameworks, voluntary standards/certification schemes, scorecards).

Table 1. Previous literature

Research focus	Author	Number of papers reviewed	Time	Source	Sustainable dimensions				
					S	Ec.	E	P	T
Biodiesel supply chain studies	(Van Cauwenbergh et al. 2007)	25	1993-2006	EE	x	x	x		
	(Mekhilef et al. 2011)	30	2006-2010	RSER		x	x		
Quantitative approaches (Models and metrics)	(Malça & Freire 2011)	28	1992-2010	RSER			x		
	(Cherubini & Strømman 2011)	45	1997-2010	BTJ			x		x
	(Cucek & Kravanja 2012)	15	2005-2011	JCP			x		
Sustainability frameworks of criteria and indicators for bioenergy and biofuels	(Cramer et al. 2007a)	8	1995-2007	Report	x		x		
	(FAO & BEFSCI 2007b)	20	1995-2006	Report	x	x	x		
	(Buchholz et al. 2009)	12	1996-2008	JCP	x	x	x		
	(Buytaert et al. 2011)	20	1991-2010	RSER	x	x	x	x	
	(Musango & Brent 2011)	30	1995-2010	ESD	x	x	x		x
	(Kurka & Blackwood 2013)	41	1999-2012	RSER	x	x	x		x
	(Mata et al. 2013)	49	2003-2012	SERA	x	x	x		
	(Florin et al. 2013)	50	1996-2013	ESP	x	x	x	x	
Sustainability Initiatives (regulatory frameworks, voluntary standards, certification schemes, scorecards)	(Fritsche et al. 2006)	35	1990-2006	Book	x		x		
	(FAO & BEFSCI 2011)	26	1998-2011	Report	x	x	x	x	
	(Scarlat & Dallemard 2011)	18	1999-2010	EP	x	x	x	x	

RSER-Renewable and Sustainable Energy Reviews
 EE-Ecosystems and Environment
 SERA-Sustainable Energy Technologies and Assessments
 JCP-Journal of Cleaner Production

ESP-Environmental science and policy
 ESD-Energy of Sustainable Development
 EP-Energy Policy
 BTJ-Bioresource Technology journal

With regard to the biodiesel supply chain studies, the documents show that the biomass sourcing network issues were often analysed (Van Cauwenbergh et al. 2007; Mekhilef, Siga, and Saidur 2011). The literature also shows that most of the quantitative approaches were linked to life cycle studies (Cherubini and Strømman 2011; Malça and Freire 2011) and to footprint computation tools (Cucek and Kravanja 2012).

On the other hand, holistic approaches of sustainability frameworks of criteria and indicators for bioenergy and biofuels were proposed by multiple research works; the earliest related literature review was Cramer et al. (2007a), who proposed a set of sustainability criteria and indicators about environmental and social themes. Kurka et al. (2013) also proposed criteria and indicators for bioenergy development. Buchholz et al. (2009) considered only sustainability criteria, and Musango et al. (2011) added a conceptual framework with a system dynamics approach to technology sustainability assessment. Similarly, Mata et al. (2013) proposed a sustainability analysis of biofuels through the supply chain using indicators and Florin et al. (2013) presented an indicator assessment of biofuel production systems.

Concerning sustainability initiatives (regulatory frameworks, voluntary standards, certification schemes, scorecards) proposals were linked to sustainability assessment of biofuels, including goals, principles, criteria and indicators. FAO & BEFSCI (2011) proposed a set of tools that included classification, certification, standardization, and lifecycle assessments of biofuels. Additionally, authors identified sustainability standards for bioenergy (Fritsche et al. 2006) and a global overview about development of biofuels /

bioenergy sustainability certification (Scarlat & Dallemand 2011). The sustainability initiatives had in common their sustainability objectives, though the assessment approach and metrics showed important differences, so comprehensive integration was difficult.

From the sustainability dimensions considered by the different types of documents, the literature reviews reflect that social, economic and environmental dimensions were frequently considered. The political dimension has been taken into account by sustainability initiatives (regulatory frameworks, voluntary standards, certification schemes and scorecards). The technological dimension is mostly included in sustainability frameworks of criteria and indicators for bioenergy and biofuels.

Regarding the research focus in the previous literature reviews, and with the aim of proposing a new hierarchical sustainability assessment framework of biodiesel production, the following research questions were considered:

- Which sustainability dimension should be part of a sustainability assessment framework?
- How is the current sustainability assessment framework structured?
- What component could be proposed for a sustainability assessment framework?

To provide an answer to these questions, this work developed a comprehensive state of the art, following a search strategy of material collection and descriptive analysis, taking the previous literature review (Table 1) as a starting point.

2. Methods

A systematic literature review method composed by a search strategy and analysis of the collected documents has been deployed. This method is described as follows:

2.1 Search strategy of documents

To determine the state of the art required to perform the sustainability assessment of biodiesel production, a search strategy considers: (1) defining the type of documents and keywords to perform the search in databases, (2) establishing the sources of information to be employed (databases and organizations websites), and (3) delimiting the time interval to be explored.

(1) The type of documents to be considered include:

- Methods, structures, systems, certifications, standards and regulatory frameworks that incorporate goals, objectives or principles, criteria and indicators, or verifiably assess the sustainability of the biodiesel production.
- Research reports, articles in journals, project reports and PhD memories about sustainable biodiesel production. Those studies should at least consider the traditional dimensions of sustainable development (social, economic and environmental).
- Research reports, articles in journals, project reports and theses about one or more stages of the biodiesel supply chain.

(2) The keywords considered for the search in databases and organizations' websites were:

- Biofuel certification, biofuels initiatives.
- Biofuel sustainability criteria and indicator.
- Biofuel standards, policies and scorecard.

- Biofuel sustainability assessment framework.

The sources of information to be employed (databases and organizations' websites):

- Academic and research institution websites.
- Websites of governmental and non-governmental institutions working on sustainability assessment of biodiesel.
- Scientific databases included in the Web of Science and Scopus, in particular the following journals' databases: American Chemical Society ACS, Science Direct, Springer Journal, and Nature.com.

(3) The period of information searching: It begins in 2000 and finishes in 2014. This was defined as the initial year of the period because a constant growth in biodiesel production at the global level as well as higher market prices were observed since 2000 (OECD and FAO 2014).

2.2 Descriptive document analysis and selection

The descriptive analysis of the state of the art was made with the aim to know the temporal distribution of documents determined by the set of keywords, as well as document distribution by information sources, the subject area in information sources and the sustainability assessment dimensions; also the keywords, the most recurrent by geographical regions.

Afterwards, the document selection was carried out through a deductive process, considering the three research questions of this work and the search strategy. Initially, the document must incorporate at least two of the following concepts: goals, objectives or principles, criteria, indicators or verifiable. After that, the document should at least consider the traditional dimensions of sustainable development (social, economic and environmental). Finally, the document should take into account the sustainability assessment framework. If the identified document in the search strategy complies with two or more previous conditions then the document is selected.

3. Results from the literature review

The results of the method described above are first presented through a descriptive analysis. Then the documents are selected and their classification by document type is proposed. Subsequently, implications of the results regarding the sustainability dimensions that were defined in the present work are discussed. Finally, a discussion on the general frameworks proposed by the literature is proposed.

3.1 Descriptive analysis

Overall, it could be indicated that the sustainability assessment of biofuel production is a research topic that has been strongly developed in the last 10 years. This aspect is shown in Figure 1; in total, 411 different documents were identified. From 2003 until 2009, the number of documents increased by 50% per year. Then, from 2009 to 2014 the documents increased approximately 40%, with a significant number of documents about biofuel policies in 2013. The use of “biofuel and sustainability criteria” as a keyword presented constant growth until 2007, similar to the keyword “biofuel sustainable assessment framework”. The document’s temporal distribution showed that the keyword “biofuel certification or biofuels initiatives”

(regulatory frameworks, voluntary standards/certification schemes, scorecards) was seen since 2003 and continued to be included as a keyword until 2014.

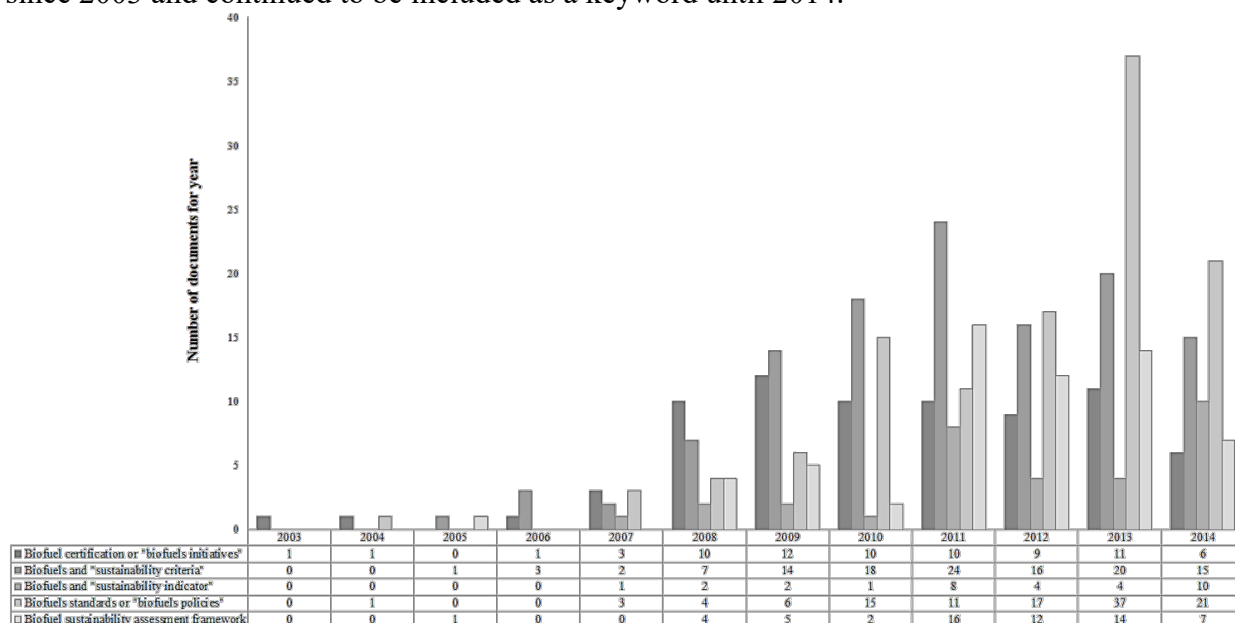


Figure 1. Document temporal distribution

The information sources were highly diverse, with 159 different journals and approximately 50 websites of governmental and non-governmental institutions being identified. The information sources with the most number of documents published are shown in Figure 2. The journal *Energy Policy* and the institutions' websites were highlighted regarding the keyword “biofuels standards or biofuels policies”. The keyword “biofuels and sustainability criteria” also had a significant number of documents published in the journal *Biofuels, Bioproducts and Biorefining*. Furthermore, the institutional website show a high number of documents related to models of biofuels’ certification and sustainable initiatives, because these institutions promote and in some case grant certification adopted by biofuels supply chain stakeholders. Regarding to energy, biofuels and policy journals, the keyword resulting in the highest number of documents was *biofuels standards*. As a consequence, the influence of standards and policies on the promotion of sustainable biofuels production has been extensively analyzed by peer reviewed scientific documents.

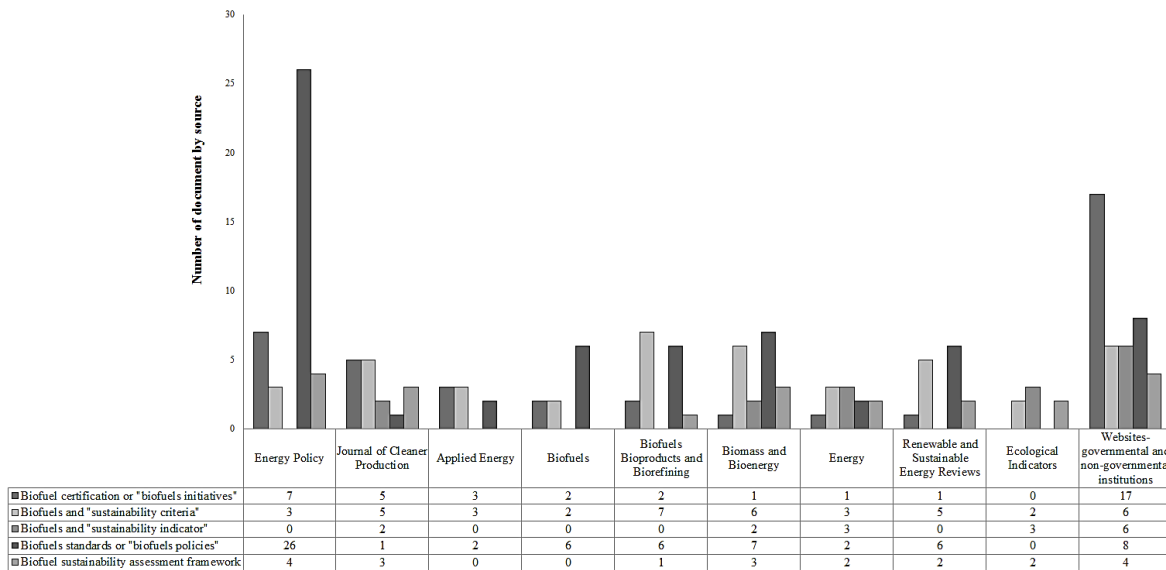


Figure 2. Distribution of document in the information sources

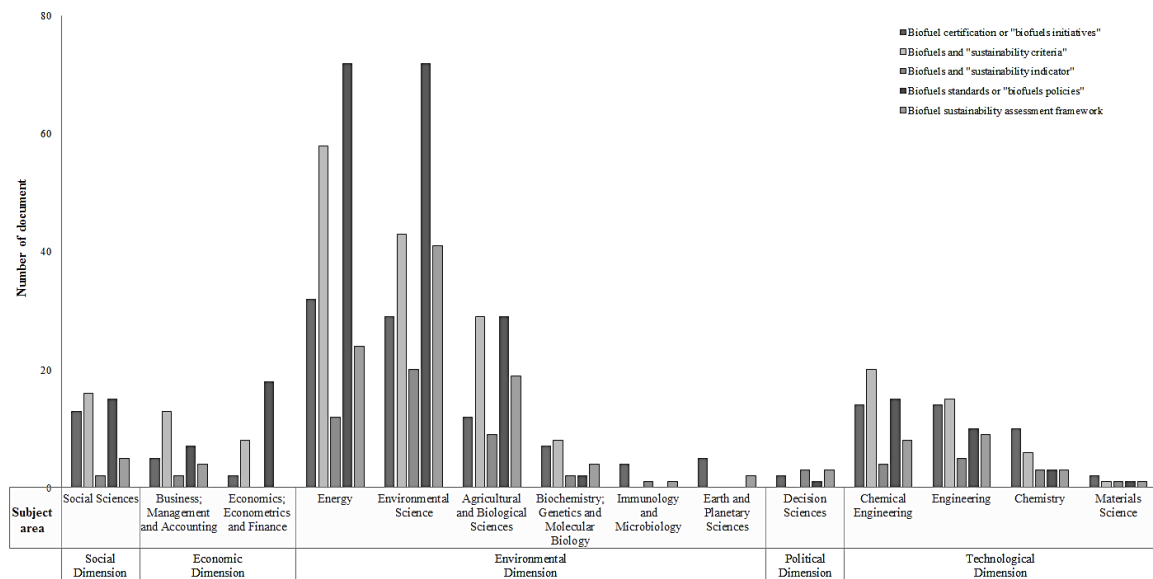


Figure 3 shows the documents' distribution per "subject area". The subject areas applied in this work were selected taking into account the abstract and citation database Scopus, which has a coverage span of 27 subject areas. Thus, each identified document was linked to a subject area, and the subject areas were associated with the sustainability dimensions used in previous literature reviews for biofuel assessment (see Table 1). The subject areas having the highest number of related documents are those of the environmental dimension: energy, environmental science, agricultural biological science, chemical engineering and engineering. Moreover, the sustainability assessment dimensions with significant subject areas and documents published were environmental and technology dimensions, while a moderate number of subject areas and documents were found for economic and social dimensions. The lowest number was found for the political dimension. It is interesting to observe that the keywords *biofuel standards* or *biofuel policies* obtained a high number of documents published in the subject areas energy and environmental sciences.

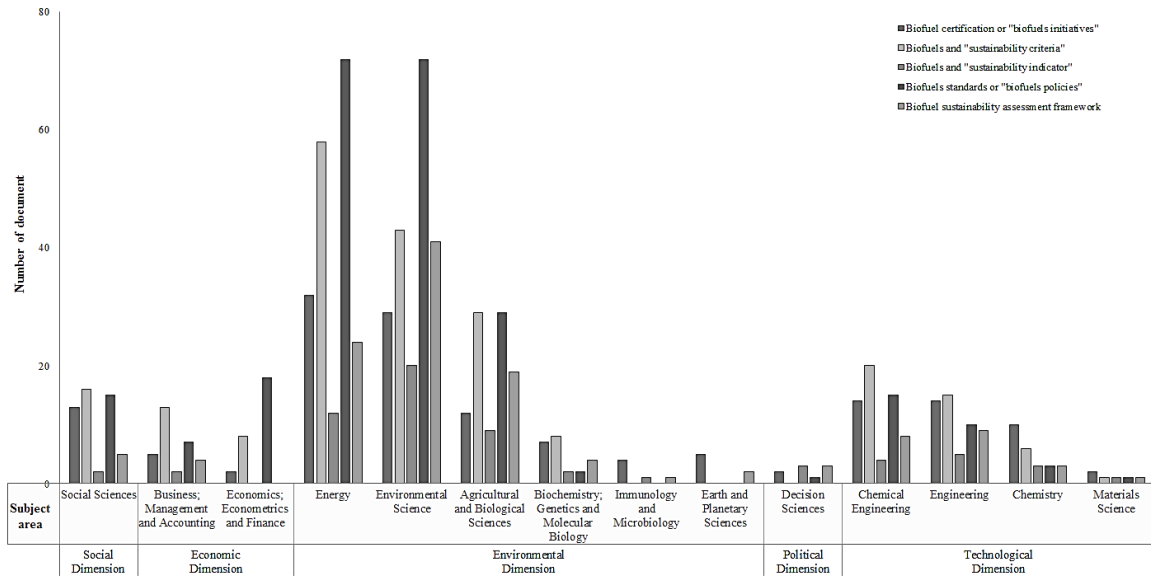


Figure 3. Documents by subject area

To conclude, the geographical distribution of documents by region shows that Europe was the region with the highest number of publications from 2003 to 2014. The most relevant keyword was “biofuels and sustainability criteria”. For the second region, North America (United States and Canada), and the third region, Asia, the relevant keyword was “biofuels standards and biofuels policies”. The fourth region was Latin America, with a similar number of documents in the five keywords (see

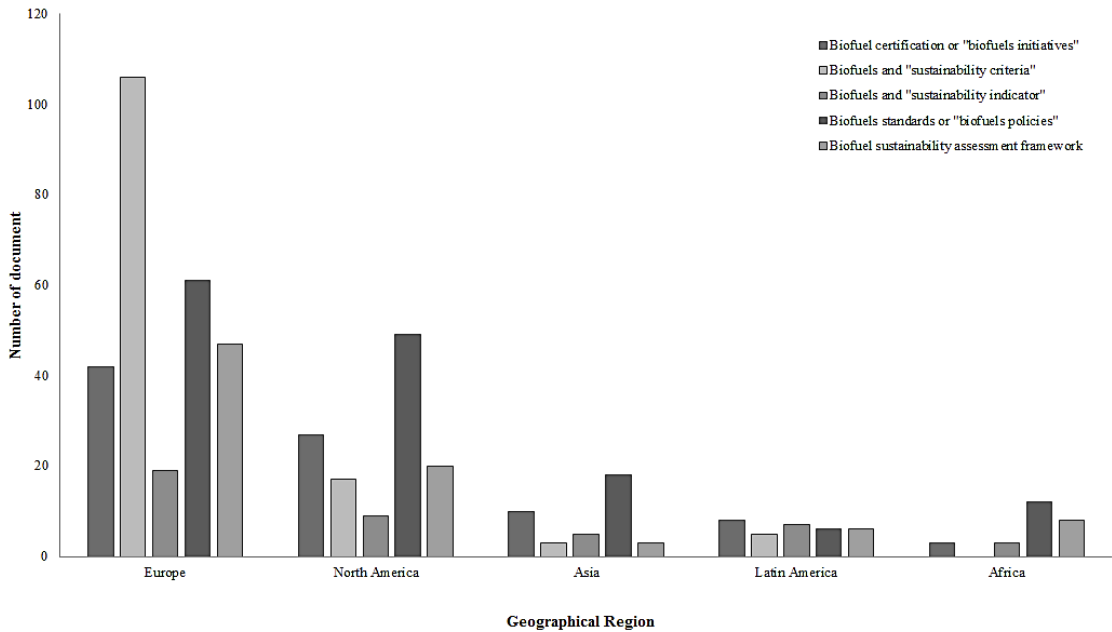


Figure 4). It was highlighted that the European region and the United States are the principal biofuel producers and consumers, and the Asian – Latin American regions are the important potential expansion areas for biofuel production (Energy Information Administration 2011).

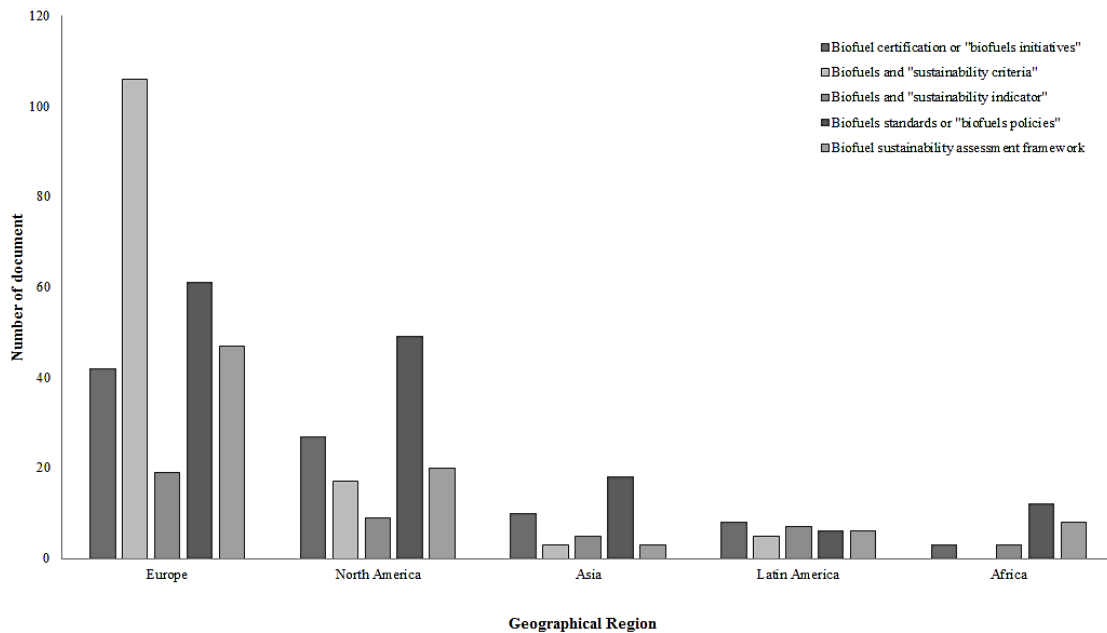


Figure 4. Geographical distribution of documents

3.2 Information Classification

As a result of the selection process described in section 2.2, 103 documents met the selection conditions and were classified in four groups according to the type of documents. The first group includes biofuel certification standards and sustainability initiatives (regulatory frameworks, voluntary standards/certification schemes, scorecards). The second group corresponds to documents where biofuel sustainability criteria and indicators were presented. The third group corresponds to biofuel standards and policies that aim at sustainability of the biofuel production chain and its stakeholders. Finally, the fourth group contains documents about biofuel testing frameworks and scorecards. The selected documents and their classifications are shown in Table 2.

As may be seen from Figure 5, the greatest number of studies corresponds to papers published in peer-reviewed journals, 45% of these studies. The second proportion, 40%, was obtained by certification and initiatives of sustainability criteria of biofuels. The third are biofuel standards and policies, at 12% of the studies. The fourth, 3% of the studies, are testing frameworks and biofuel scorecards carried out by governmental and non-governmental organizations.

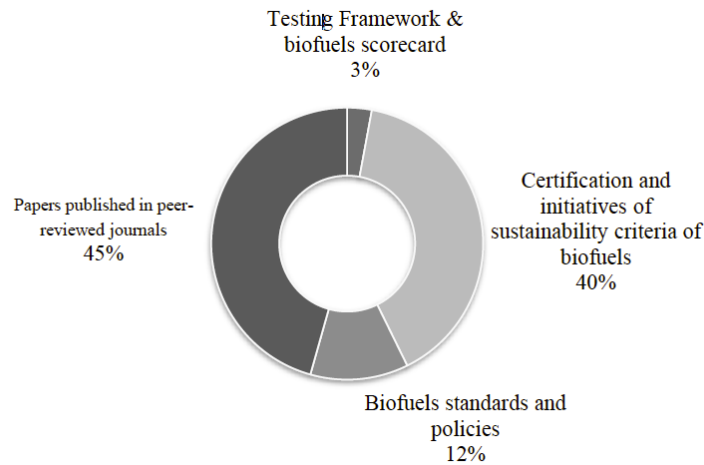


Figure 5. Percentages of document by classification group of documents.

Comparing the document temporal distribution (Figure 1), the distribution of documents by information source (Figure 2) and the document by subject area (Figure 3), it is observed in Figure 5 that there is a parallel trend of research made by scientific community through peer-reviewed journals (Figure 1 and 3) and the research application by means of certification and voluntary initiatives of sustainable biofuels production promoted by Government and non-governmental organizations or institutions (websites in Figure 2). This trend is positive because the scientific research can strengthen the certification processes and vice versa.

Classification groups	Selected Documents	
Certification and initiatives of sustainability criteria of biofuels	1. Bonsucro, Better Sugarcane Initiative.	21. SAN/RA, Sustainable Agriculture Network/Rainforest Alliance
	2. FLO, Fair Trade, Fairtrade Organizations International	22. Sustainability criteria and indicators for bioenergy developed by FBOMS
	3. GQA, Genesis Quality Assurance	23. Summary IATP Sustainable Biomass Production Principles & Practices
	4. PEFC, Program for the Endorsement of Forest Certification schemes	24. ACCS, Assured Combinable Crops Scheme
	5. RTRS, Roundtable for Responsible Soy Production	25. CSBP, Council on Sustainable Biomass Production, the United States.
	6. GGLS2, Green Gold Label 2. Agriculture Source Criteria	26. NTA 8080, Sustainable Production of Biomass—The Netherlands
	7. Nordic Eco-labelling of Fuels	27. FSC, Forest Stewardship Council
	8. UNCTAD Biofuels Initiative, 2006	28. GAP, Global Partnership for Good Agricultural Practice
	9. Certification by the standardization institute NEN and the Rotterdam Climate Initiative (RCI) to assess the sustainability requirements for solid, liquid and gaseous biomass for energy application and transport fuels, Netherlands, 2011	29. IFOAM, International Federation of Organic Agriculture Movements
	10. RTFC, Renewable Transport Fuel Certificate	30. LEAF, Linking Environment and Farming
	11. BLE, Sustainable Biomass Production. Germany	31. SAI, Social Accountability International
	12. EcoLogoM, has criteria for renewable energy sources with specific criteria for biomass and biogas, Canada, 1988	32. Sustainability
	13. LEI, the Lembaga Ekolabel Indonesia, 2005	33. Guide in Biomass Production and Processing in the Biofuel chain in Colombia
	14. MTCC, the Malaysian Timber Certification Council, 2005	34. ISO 26000 – Responsibility social.
		35. ISO 14040 - Life Cycle Assessment
		36. GBEP, Global Bioenergy Partnership, 2005
		37. UNEP, 2009. Towards Sustainable Production and
		38. Use of Resources: Assessing Biofuels

Classification groups	Selected Documents			
	15. RSPO, Roundtable on Sustainable Palm Oil, 2007 16. ELECTRABEL Label Green. Development of ecological standards for biomass in the framework of green electricity labelling. Belgian regions, 2006. 17. EUGENE (EU), Project Focus on end part of chain. Actual label, adds extra principles for biomass in specific. 18. Social Fuel seal – Brazil 19. Southern African NGO position on Biofuels 20. ISCC, International Sustainability and Carbon Certification	39. USAID, Biofuels in Asia: an analysis of sustainability options. United States Agency for International Development. 40. RSB, Roundtable on Sustainable Biofuels, established by the Ecole Polytechnique Fédérale de Lausanne (EPFL) Energy Center in 2006 41. Pilot Testing of GBEP Sustainability Indicators for Bioenergy in Colombia (FAO 2014).		
Biofuels standards and policies	1. RTFO, Renewable Transport Fuel Obligation – UK 2. CAP, Common Agricultural Policy 3. Directive 2009/28/EC of the European Union, directive on renewable energy. 4. BLCAO, Biofuels life cycle assessment ordinance Swiss Confederation 5. BioNa Dv, Biomass Sustainability order, Germany 6. Biodiesel standard, ASTM D6751 and the EU's EN. 14214:2003	7. ASTM D6751 was drafted for Biodiesel fuel blends. 8. RFS2, Renewable Fuel Standard, the United States, 2010 9. WTO rules and principles (UN 2008) 10. LCFS, Low Carbon Fuel Standard (LCFS), required by California, United States. 11. SBA, Sustainable Biodiesel Alliance, in the United States, 2009 12. RFQD, Revised Fuel Quality Directive of the European Union, 2008		
Papers published in peer-reviewed journals	1. (Florin et al. 2013) 2. (Brent & Musango 2013) ; 3. (Kurka & Blackwood 2013); 4. (Pesqueira & Glasbergen 2013); 5. (FAO 2013); 6. (Elibehri et al. 2013); 7. (Mangoyana et al. 2013); 8. (Milazzo et al. 2013); 9. (German & Schoneveld 2012); 10. (BID & MMEC 2012) 11. (Musango et al. 2012); 12. (FAO & BEFSCI 2012) ; 13. (Scarlat & Dallemand 2011); 14. (Halog & Manik 2011); 15. (McBride et al. 2011) 16. (FAO & BEFSCI 2011)	17. (Gnansounou 2011) 18. (Oviedo et al. 2011) 19. (Zapata et al. 2011) 20. (WEC 2010) 21. (Boons & Mendoza 2010) 22. (Markevičius et al. 2010) 23. (Lendle & Schaus 2010) 24. (Hoon & Gan 2010) 25. (van Dam et al. 2010) 26. (Buchholz et al. 2009) 27. (Brent 2009) 28. (Delzeit & Holm-Müller 2009) 29. (Franco & Flórez 2009) 30. (Groom et al. 2008) 31. (van Dam et al. 2008) 32. (UN 2008)	33. (EC and BTG 2008) 34. (Dehue et al. 2007) 35. (Cramer et al. 2007) 36. (FAO & BEFSCI 2007) 37. (Allen 2007) 38. (Van Cauwenbergh et al. 2007) 39. (Bantz & Deaton 2006) 40. (Moret et al. 2006) 41. (Fritsche et al. 2006) 42. (Oehme 2006) 43. (Lewandowski & Faaij 2006) 44. (Clark & Macquarrie 2002) 45. (NRTEE 1999) 46. (Mendoza et al. 1999) 47. (Bueren & Blom 1996)	
Testing Framework & scorecard	1. Inter-American Development Bank Sustainability Scorecard 2. World Bank/WWF Biofuels environmental sustainability scorecard 3. Sustainability Assessment Framework (de Lange and Wolvekamp 2006)			

Table 2 Classification of selected documents

Regarding the 103 selected documents, a set of criteria and indicators was identified and a number of documents were associated with each criterion (see Annex 1). The more cited criteria are those of the environmental dimension, mainly associated with assessment of greenhouse gas emissions, air quality, water quality and quantity, and waste management. Second, the criteria of the social dimension related to aspects of rural development, compliance with labour laws, and food security. Taking third place in citations are criteria of the political dimension in areas such as compliance with local laws, ethics and transparency. Those criteria with lower levels of document citation were those associated with economic aspects such as influence on the production volume of first-generation biodiesel (from edible feedstock) of the oil market and advanced biodiesel. Criteria belonging to the technological dimension are those that obtained the lower number of citations (see Figure 6).

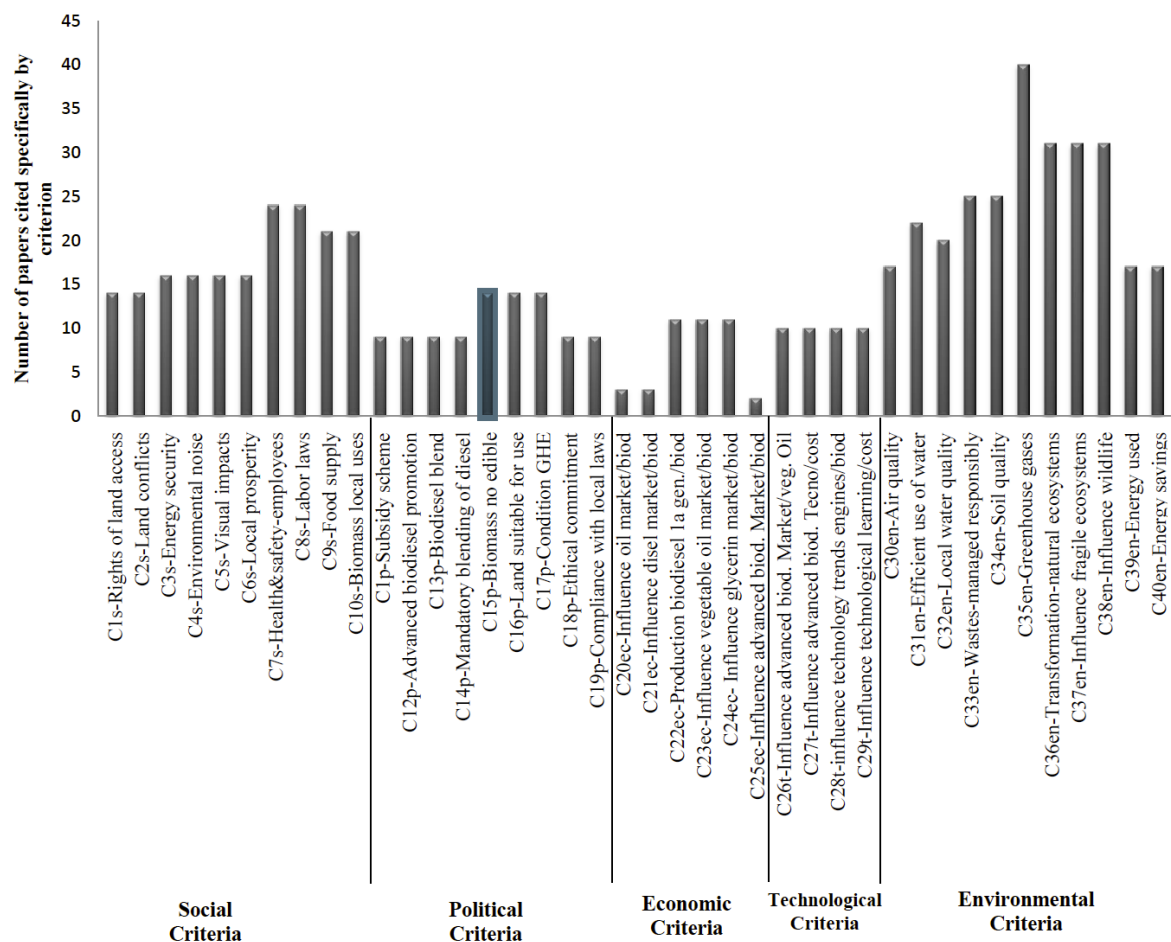


Figure 6. Number of papers cited specifically by criterion.

3.3 Sustainability assessment dimensions

The adoption of sustainability assessment should implement a holistic perspective by comprehensively/simultaneously/equally considering the relevant/full range of ‘dimensions’, since decision-makers and other stakeholders wish to be informed of the full spectrum of impact. Associated with sustainability assessment, the environmental, social and economic

dimensions are sometimes referred to as the ‘three pillars’ of sustainability or the ‘triple bottom-lines – TBL’ (Hacking and Guthrie 2008). The TBL is an approach which encompasses the three dimensions of sustainability and is linked to the strong theoretical fit for measuring multidimensionality of sustainability. These dimensions should be treated differently but eventually integrated. Sustainability can be achieved by a systematically linked “socio-economic-environmental system” and not by a single component (Lee et al. 2012).

According to the sustainability dimensions studied, 43% of the selected documents were related to the environmental dimension, 29% to social dimensions and 16% to the economic dimension. Additionally, 7% and 5% of the documents perform political or technological assessments, respectively. Based on that behaviour, we consider it necessary to add the last two dimensions to the traditional TBL sustainability assessment.

In particular for biodiesel production assessment, the political dimension is highly relevant because the Government’s policies are essential to promote the biodiesel production, creating economic conditions and favorable markets such as subsidies, taxes exemptions, and biodiesel compulsory consumption as a diesel mixture. Moreover, the technological dimension is also relevant in the sustainability assessment of biodiesel, taking into account that emerging technologies are competing with the first generation biodiesel. Furthermore, the incorporation of political and technological dimension adds additional challenges to sustainability assessment associated with indicators maturity. The political and technological indicators do not have the similar maturity as the economic or environmental indicators, for this reason, the assessment framework proposed in this work will be validated through expert consultation; the results of the validation process are currently being prepared.

The inclusion of the political dimension in sustainability assessment makes it possible to perform an analysis on the impact of the implementation of local or international regulatory frameworks, mandatory or voluntary biofuel certification systems, and the impact on the social, economic and environmental dimensions (Schade and Wiesenthal 2011). For example, the manner in which direct policy controls, such as renewable fuel standards and mandatory blending, increase the demand for biodiesel, which generates growth of biodiesel processors, increasing the demand of cultivation land for raw materials, changes in the ownership of land, impact on rural employment and changes in the quality of life and living conditions of communities associated with the biodiesel production chain.

The inclusion of the technological dimension permits the analysis of the influence of new technological developments on the sustainability of the biodiesel supply chain. Some examples of new technological trends are the use of non-edible vegetable oils as raw materials, the implementation of intensified production technologies, the production of non-ester biodiesel and changes in the internal combustion engine (Mohr and Raman 2013; Wit et al. 2010). Those aspects are fundamental for assessing the impact of implementing such technology trends on environmental and social impacts. For example, including the technological dimension could help answer questions about how new technologies could change the use of first generation biofuels in the future, if it will have a positive impact on social and environmental dimensions. This also takes into account that the use of food crops and oils for producing fuel was promoted, the “food vs. fuel” conflict and concerns about the negative impacts of monocultures for first generation biofuels on biodiversity and water conservation especially linked to the conversion of natural terrestrial ecosystems, respectively.

This research proposes to integrate the political and technological dimensions into the three traditional sustainability dimensions (environmental, social and economic), with the aim of strengthening the multidimensional sustainability assessment. The approach covers five dimensions and was named Triple Bottom Line Extended (TBL+).

3.4 Frameworks previously used for sustainability assessment of biofuels

According to the state of the art, three different types of frameworks to perform the sustainability assessment of biodiesel have been identified. These frameworks are shown in

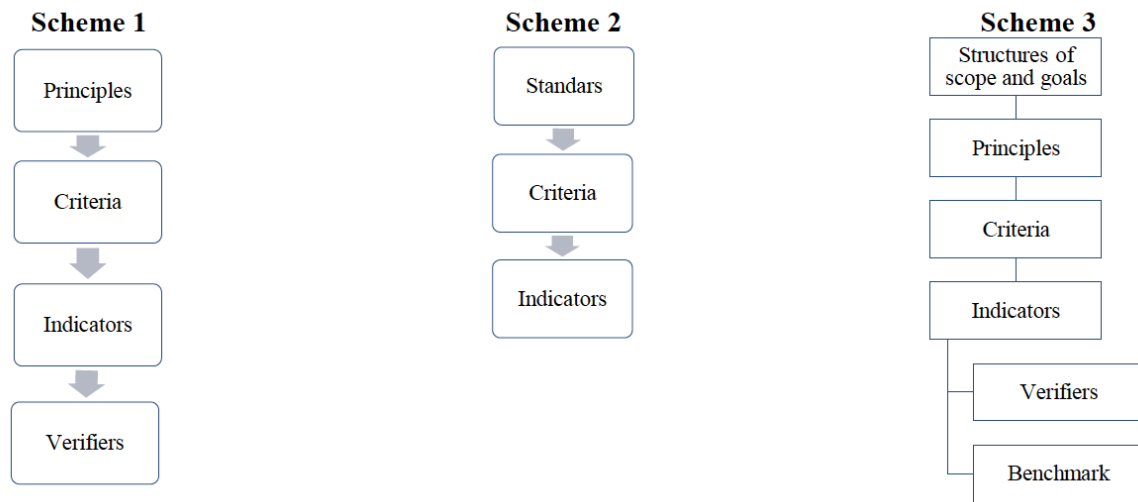


Figure 7.

Scheme 1 defines a set of principles, which are described by a number of criteria. Each criterion has a set of indicators that are calculated using verifiers. Principles are ‘universal’ basic facts or attributes of a sustainable system (Florin, van de Ven, and van Ittersum 2013). A criterion is a translation of the principle into concrete requirements that have to be met (Cramer et al. 2007b). Indicators are the concrete and quantifiable aspects that will be used in the evaluation procedure (FAO and BEFSCI 2007). The verifiers provide additional data or information that enhances the specificity of the ease of assessment of an indicator (Buytaert et al. 2011). Sometimes verifiers are defined to double-check the indicators (E. C. EC and BTG 2008) and are also needed for indicator assessment and the control of the fulfilment of sustainability criteria (Lewandowski and Faaij 2006).

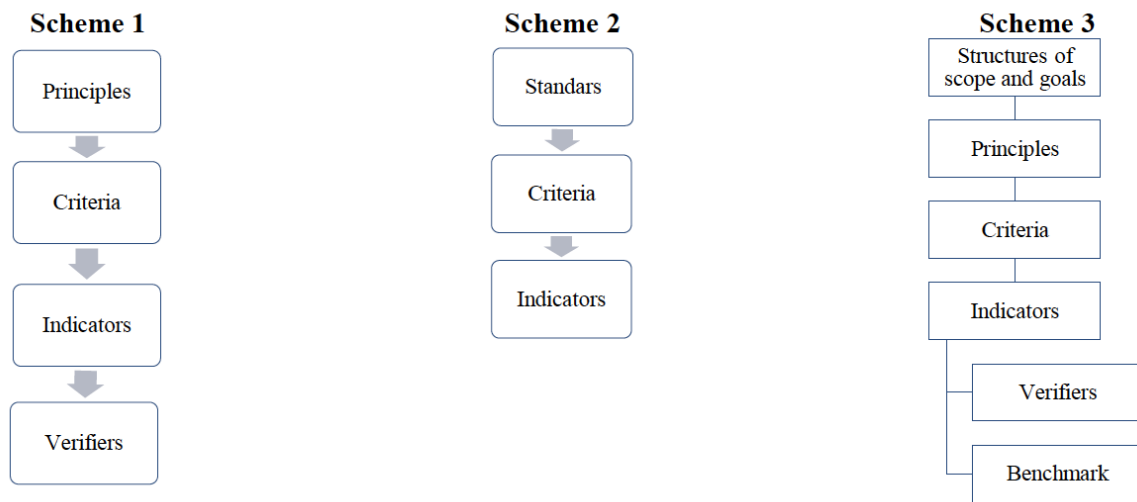


Figure 7, is commonly used in international certification systems and defines a set of standards which are assessed by criteria; each criterion has a set of indicators (van Dam et al. 2008b). The standards are meant as basic principles for defining the “rules” which sustainable bioenergy development should follow (Fritsche et al. 2006). At the same time, the standards are a set of predetermined requirements that are assessed in certification processes (Scarlat 2011). The definition of criteria and indicators in Scheme 2 are the same as those referred to above.

Scheme 3 is generally used in life cycle assessment - LCA; initially the organizational set-up needs to be established through goal and scope definitions, taking the stakeholders into account. The goal and scope definition is the phase in which the initial choices which determine the working plan of the entire LCA are made. The goal of the study is formulated in terms of the exact question, target audience and intended application. The scope of the study is defined in terms of temporal, geographical and technological coverage, and the level of sophistication of the study in relation to its goal (Guinée and Tukker 2002). Each goal is described by principles and the principles are described by a set of criteria, likewise the criteria by a number of indicators. Each indicator is measured by verifiers, or judged through standards or references called benchmarks (van Dam et al. 2008a)

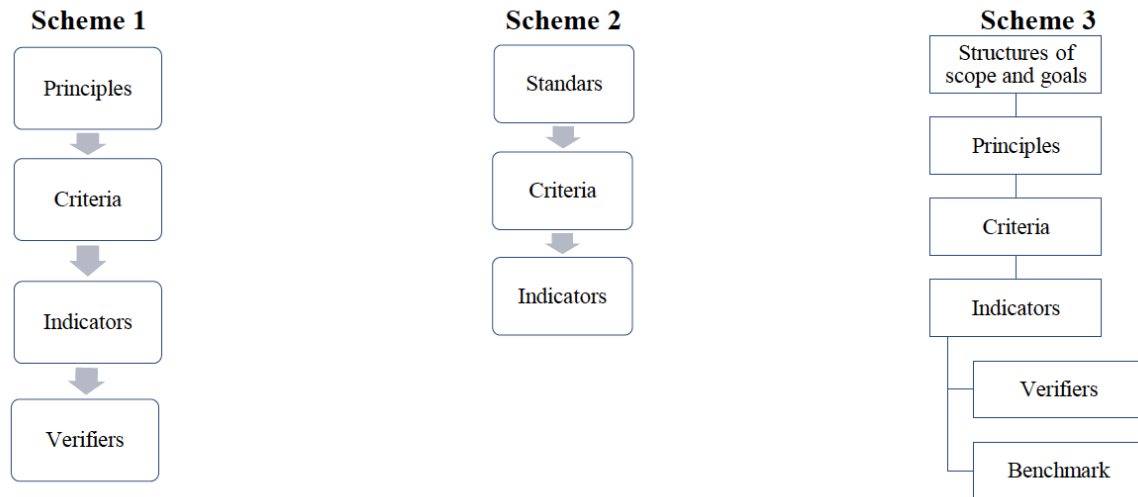


Figure 7. General frameworks employed to perform the sustainability assessment of biodiesel. The three schemes described are mutually complimentary, as all of them are related to principles, criteria and indicators (PC&I). However, some features of each scheme must be highlighted in order to apply them to the biodiesel supply chain:

- The first scheme allows proposing PC&I, to give a general framework of diagnostic and analysis for a specific case. A comprehensive analysis must be carried out in order to identify those criteria and indicators.
- In the second scheme, certifications define standards as minimal requirements, and the biofuels supply chain stakeholders fix the criteria and indicators that must be evaluated based on those standards.
- In third scheme, related to LCA analysis, it is required extensive and detailed information (databases of indicators) to quantify the impact of biofuel production chain on sustainability dimensions. Then, the PC&I are defined based on the resulting impacts.

Regarding the previous considerations, the assessment framework of PC&I proposed in this work is developed in the context of the first scheme. From our point of view, it will constitute a starting point for future reflections and proposals about standards, certifications and life cycle analysis of the biodiesel sector.

4. The Triple Bottom Line Extended (Biodiesel-TBL+), a new framework for biodiesel sustainability assessment

The framework was constituted by *principles, criteria and indicators (PC&I)*, and has a structure of four levels, which is presented subsequently in Figure 8. The concepts presented in

PRINCIPLES	CRITERIA	INDICATORS	REFERENC ES
Fundamental truth or law as the basis of reasoning or action. Principles justify the chosen criteria, indicators and verifiers	Principle or standard that a thing is judged by. Criteria enhance the meaning and operability of principles, however do not measure performance.	Used to infer the status of a particular criterion. Indicators are comprised of specific information about a criterion.	(Kurka & Blackwood 2013)
Principles are 'universal' basic truths or attributes of a sustainable system.	Criteria are the rules that govern judgment on outcomes from the system.	Means of assessing performance against criteria.	(Florin et al. 2013)

PRINCIPLES	CRITERIA	INDICATORS	REFERENC ES
Principles are usually established as general starting points that describe the objective of certification.	These objectives are then translated into measurable requirements by criteria.	Testing then utilizes indicators or verifiers, which serve as quantitative or qualitative minimum requirements for certification.	(UN 2008)
Principles are general conditions for achieving sustainability (which is the ultimate goal).	Criteria are specific objectives, more concrete than principles and relating to a state of the system, and therefore easier to assess and to link indicators.	Indicators are variables of any type that can be assessed in order to measure compliance with a criterion.	(Van Cauwenbergh et al. 2007)
A principle is the general starting point as a basis for the quality requirements.	A criterion is a translation of the principle into concrete requirements that have to be complied with.	An indicator is a qualitative or quantitative parameter, by which a criterion becomes testable. Indicators must be clear and verifiable.	(Cramer et al. 2007b)
The principles are the overarching ideas or concepts that the standard tries to aim at.	The criteria are the particular aspects that one operator has to follow in order to apply the principle.	Indicators are the concrete verifiable and quantifiable aspects that are used in the evaluation procedure.	(FAO & BEFSCI 2007b)
A fundamental truth or law as the basis of reasoning or action. They provide the justification for Criteria, Indicators and Verifiers.	A Criterion can be one that adds meaning and operationally to a principle without itself being a direct measure of performance.	An indicator is any variable or component of a system used to infer the status of a particular Criterion. Indicators should convey a 'single meaningful message'. This 'single message' is termed information.	(Mendoza et al. 1999)
A principle is a fundamental law or rule, serving as a basis for reasoning and action. Principles are explicit elements of a goal.	A criterion is a state or aspect of the dynamic process of a system, which should be in place as a result of adherence to a principle.	An indicator is a quantitative or qualitative parameter, which can be assessed in relation to a criterion. It describes in an objectively verifiable and unambiguous way features of the system.	(Bueren & Blom 1996)

Table 3 were the input to determine the following definitions used in this paper:

- *Principles*: The premises, bases or universal principles that define the sustainability of a biodiesel supply chain.
- *Criteria*: Those measurable conditions (qualitative or quantitative) that establish the level of application of the principles of a sustainable biodiesel supply chain.
- *Indicators*: are observable qualitative or quantitative expressions, which can describe the characteristics, behaviours or phenomena of reality through the development of one or more variables.

PRINCIPLES	CRITERIA	INDICATORS	REFERENC ES
Fundamental truth or law as the basis of reasoning or action. Principles justify the chosen criteria, indicators and verifiers	Principle or standard that a thing is judged by. Criteria enhance the meaning and operability of principles, however do not measure performance.	Used to infer the status of a particular criterion. Indicators are comprised of specific information about a criterion.	(Kurka & Blackwood 2013)
Principles are 'universal' basic truths or attributes of a sustainable system.	Criteria are the rules that govern judgment on outcomes from the system.	Means of assessing performance against criteria.	(Florin et al. 2013)
Principles are usually established as general starting points that describe the objective of certification.	These objectives are then translated into measurable requirements by criteria.	Testing then utilizes indicators or verifiers, which serve as quantitative or qualitative minimum requirements for certification.	(UN 2008)
Principles are general conditions for achieving sustainability (which is the ultimate goal).	Criteria are specific objectives, more concrete than principles and relating to a state of the system, and therefore easier to assess and to link indicators.	Indicators are variables of any type that can be assessed in order to measure compliance with a criterion.	(Van Cauwenbergh et al. 2007)
A principle is the general starting point as a basis for the quality requirements.	A criterion is a translation of the principle into concrete requirements that have to be complied with.	An indicator is a qualitative or quantitative parameter, by which a criterion becomes testable. Indicators must be clear and verifiable.	(Cramer et al. 2007b)

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The principles are the overarching ideas or concepts that the standard tries to aim at.	The criteria are the particular aspects that one operator has to follow in order to apply the principle.	Indicators are the concrete verifiable and quantifiable aspects that are used in the evaluation procedure.	(FAO & BEFSCI 2007b)
A fundamental truth or law as the basis of reasoning or action. They provide the justification for Criteria, Indicators and Verifiers.	A Criterion cans one that adds meaning and operationally to a principle without itself being a direct measure of performance.	An indicator is any variable or component of a system used to infer the status of a particular Criterion. Indicators should convey a 'single meaningful message'. This 'single message' is termed information.	(Mendoza et al. 1999)
A principle is a fundamental law or rule, serving as a basis for reasoning and action. Principles are explicit elements of a goal.	A criterion is a state or aspect of the dynamic process of a system, which should be in place as a result of adherence to a principle.	An indicator is a quantitative or qualitative parameter, which can be assessed in relation to a criterion. It describes in an objectively verifiable and unambiguous way features of the system.	(Bueren & Blom 1996)

Table 3. Definitions of principles, criteria and indicators

The first level in the framework was the interaction between the five dimensions of the sustainability Triple Bottom Line extended (Biodiesel-TBL+) and the biodiesel supply chain stages. In this interaction, the sustainability principles were defined. The principal stages of the supply chain considered were: feedstock plantation, storage facilities, oil extraction plants, biorefineries (feedstock transformation), biodiesel-diesel blending facilities and retail outlets (Andersen et al. 2012; Avami 2012; Awudu and Zhang 2012; Kumar and Nigmatullin 2011; Mata et al. 2013; RS 2008).

The second level was made up of a set of sustainability assessment criteria linked to each principle. These criteria were identified as a measurable condition (qualitative or quantitative) aiming to assess how the sustainability principle was applied to the biodiesel supply chain. The first and the second level in the framework were defined in order to make a general sustainability assessment. Therefore, the principles and criteria can be applied regardless of the economic, social, political or biogeographic context, the technological conditions or the raw materials used, among other aspects.

Finally, in the third level, indicators were established to evaluate the characteristics or behaviours of each criterion. Besides principles, and criteria, the indicators must refer to particular conditions of the biodiesel production chain, or the assessment scale (national, regional, local). Therefore, the framework could be applicable to specific contexts. The new framework was summarized in Figure 8.

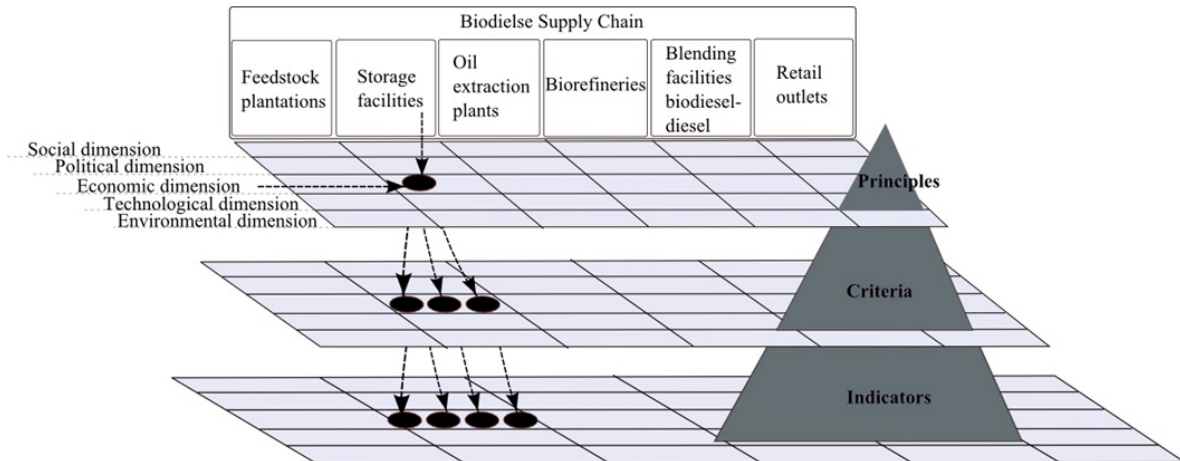


Figure 8. Biodiesel sustainability framework.

As outlined earlier, the biodiesel sustainability framework proposed covers five dimensions (Triple Bottom Line Extended-TBL+). The two additional sustainability dimensions (political and technological) were included with the aim to increased level of granularity and visibility of the principles, criteria and indicators (PC&I).

5. Application of the new assessment framework to biodiesel production

The new framework proposed was applied to the biodiesel production chain. Overall, 13 principles and 40 criteria were identified through the analysis of 103 documents selected, and their description is presented in Figures 9 to 13. Each indicator is described in Annex 1 and the references linked to each dimension are shown there.

The topics considered in the social dimension include as principles the respect of the property land rights, the social acceptability, the promotion to responsible work condition and prevention of food supply alteration. The criteria are defined to assess the conflict level that can generate the raw materials cultivation and the biodiesel production on communities. Additionally, the criteria permits to analyze the conflicts change with respect to access and tenure land, the community and workers life conditions, and their influence on social acceptability of the biodiesel production. The social principles and criteria, and its indicators are described in Figure 9 and Annex 1, respectively.

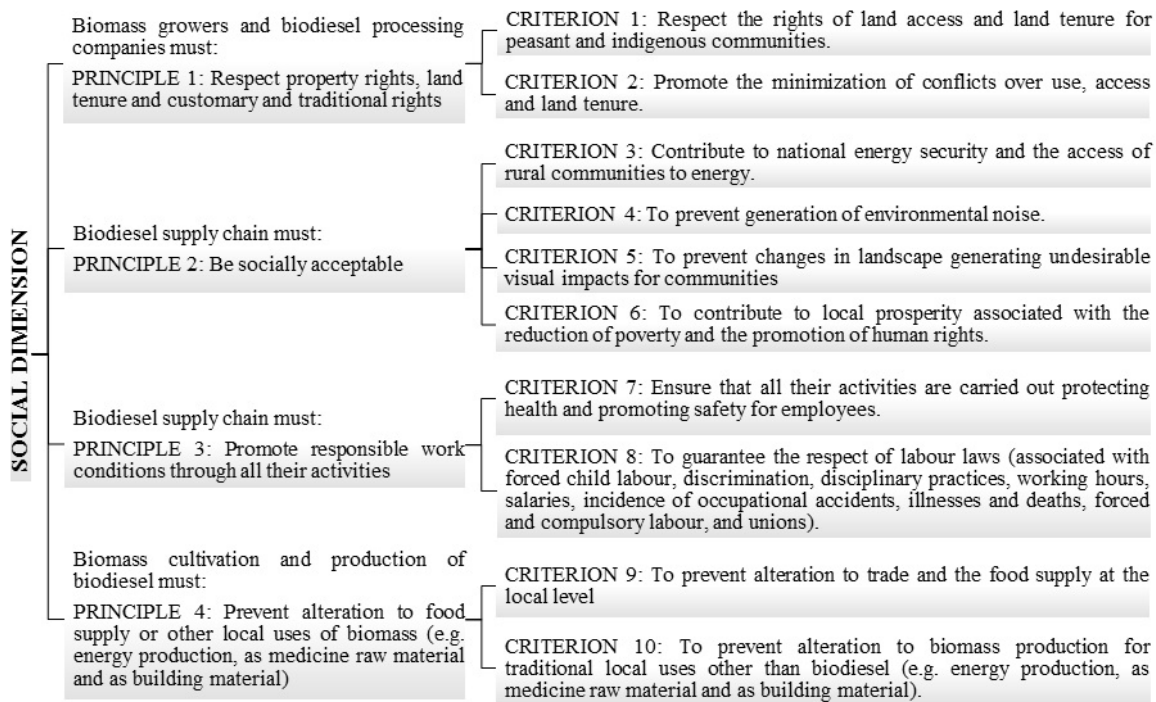


Figure 9. Social dimension: principles and criteria

The principles in political dimension are referred to the influence of national and international policies about promotion, market, and sustainable production. The political criteria seek assess the agreement between national and international subsidies schemes, advanced biodiesel production and biodiesel blend – diesel, national capability in biodiesel research and development. Also, it includes the raw material production consistent with international environmental policies, and local perception on ethical and transparency commitment by the actors in the biodiesel production chain. The social principle and criteria are described in Figure 10, and the indicator in Annex 1.

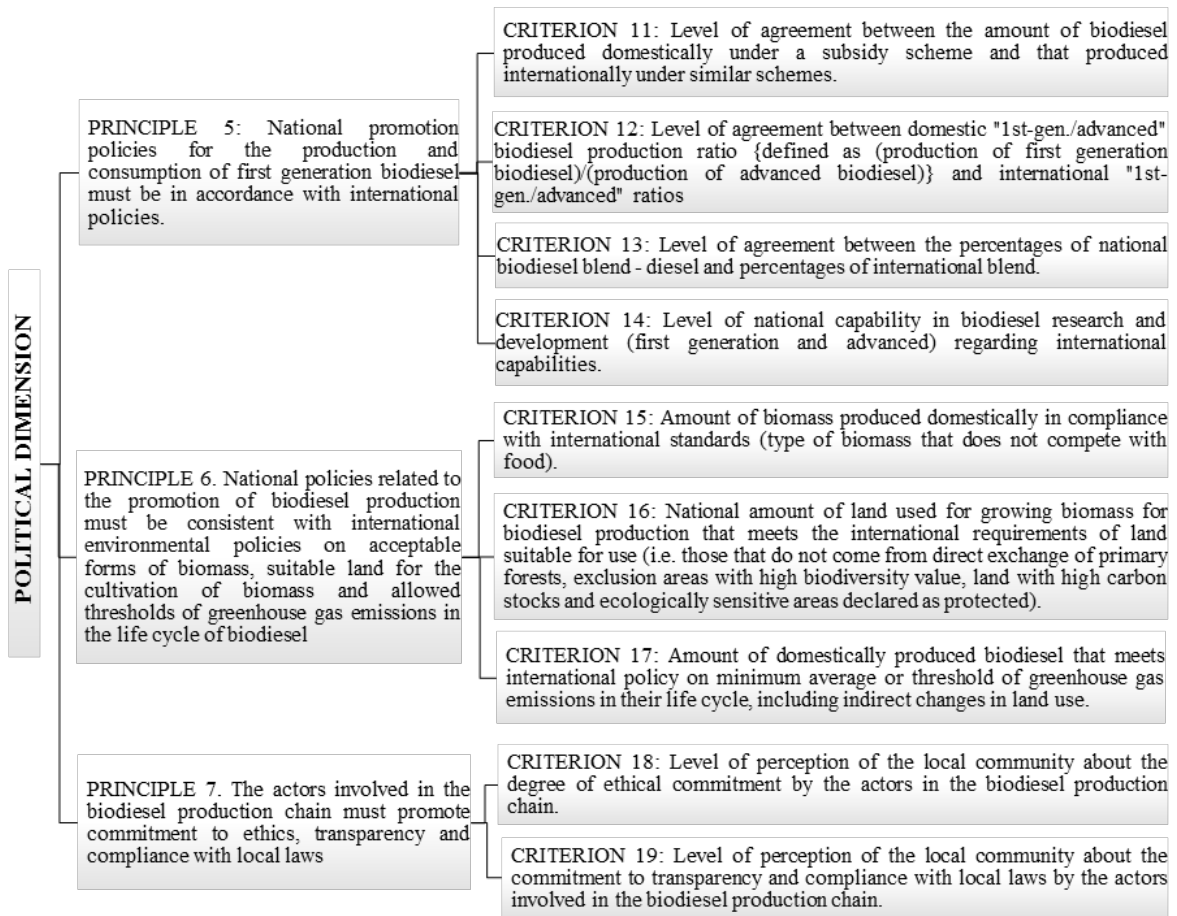


Figure 10. Political dimension: principles and criteria

The first level, economic principle, underline that biodiesel production must be sustainable at both the macroeconomic and microeconomic level. The second level, economic criteria assess the influence level of macroeconomic variables as oil market, diesel market, first, second and third generation biodiesel market, on microeconomic variables as vegetable oil price, biodiesel price and glycerin price. The economic principle and criteria are described in Figure 11. The indicators are presented in Annex 1.

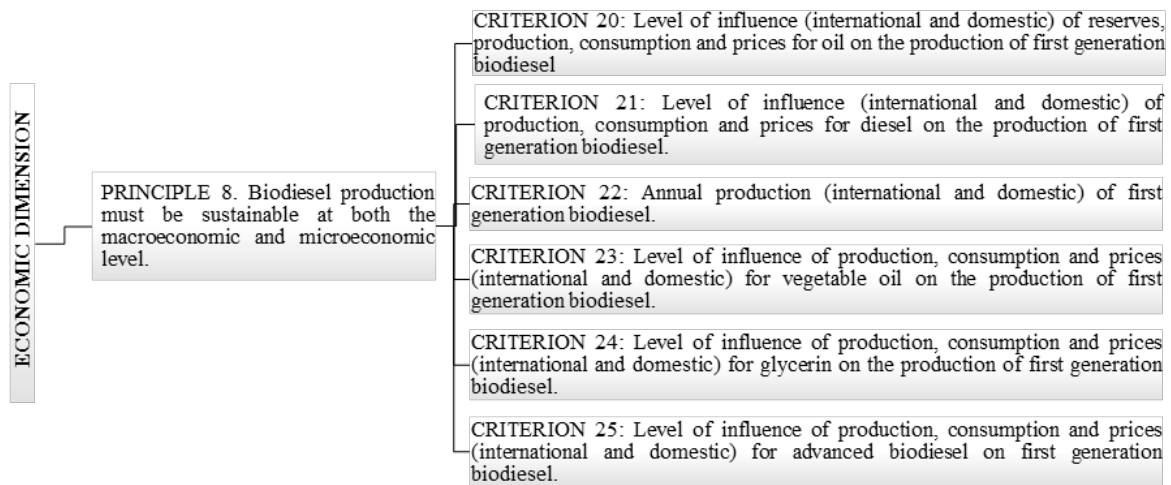


Figure 11. Economic dimension: principles and criteria

The technological principle is focused in the reduction of negative impact on environment and the efficiency and cost reduction. The criteria taking into account the influence of emerging technologies for first, second and third biodiesel production on the demand of natural resources, pollution generation, and cost reduction. Also, the criteria consider the technological learning in the first generation biodiesel linked to technological improvements and cost reduction. The technologic principles and criteria are described in Figure 12. The indicators are described in Annex 1.

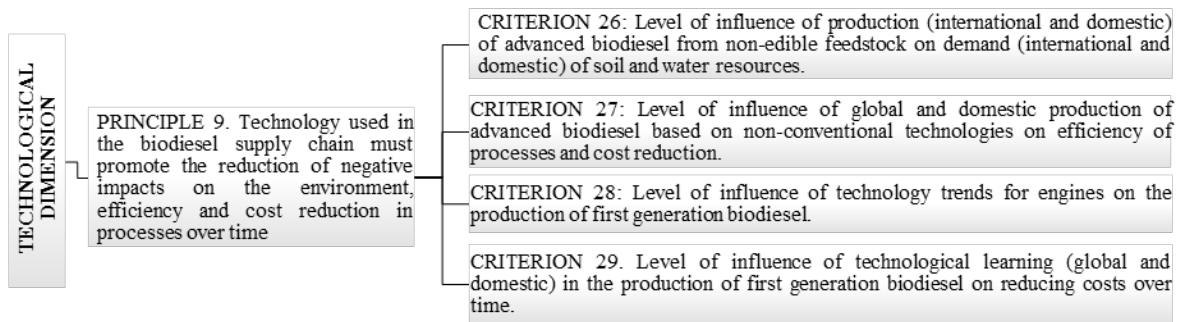


Figure 12. Technological dimension: principles and criteria

The environmental principles consider issues as air, soil and water quality, waste and wastewater management, balance of greenhouse gases, conservation and protection of biodiversity and wildlife, and energy efficiency. In general, the environmental criteria assess the influence of biodiesel supply chine on the environmental condition, the transformation of natural ecosystem and the quality of natural resources. The environmental principle and criteria are described in Figure 11. The indicators are presented in Annex 1.

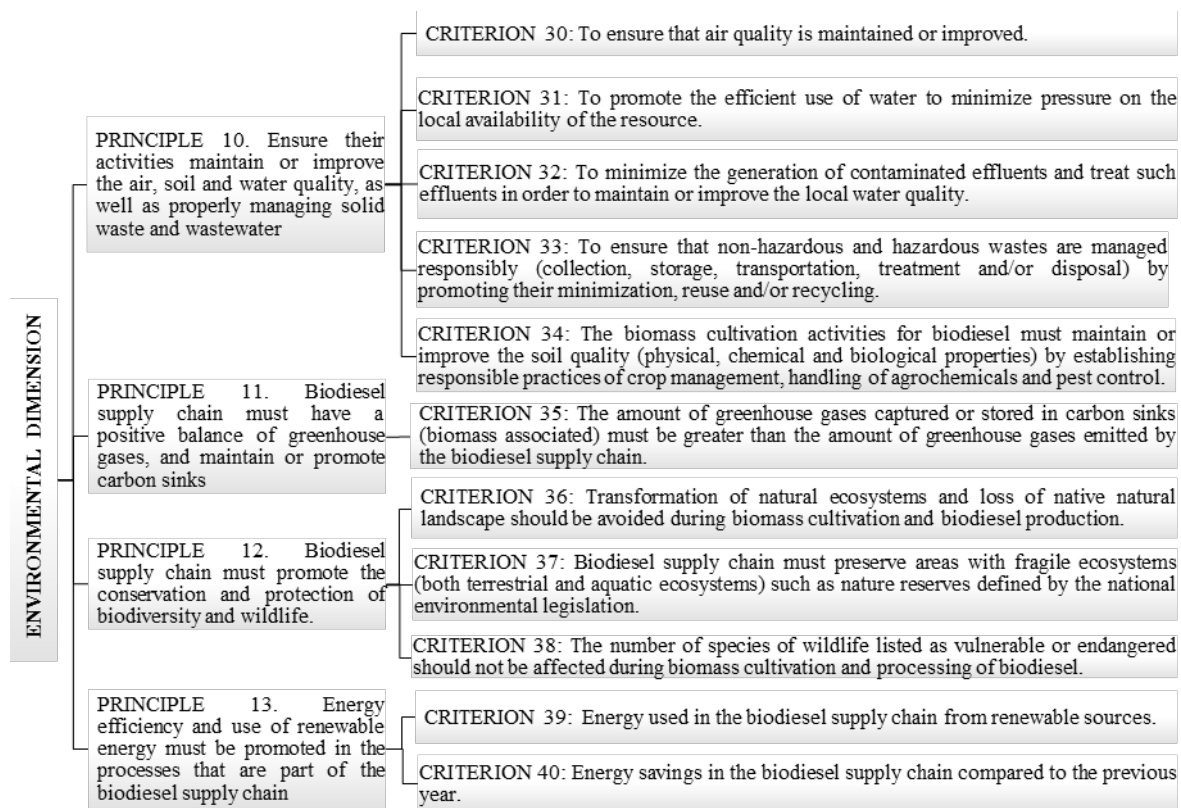


Figure 13. Environmental dimension: principles and criteria

6. Discussions

When the new framework for biodiesel sustainability assessment was compared with other similar studies (Bueren and Blom 1996; Van Cauwenbergh et al. 2007; Cramer et al. 2007a; FAO and BEFSCI 2007; Florin, van de Ven, and van Ittersum 2013; Kurka and Blackwood 2013; Mendoza et al. 1999), significant differences were found. First, the new framework considered five dimensions in the sustainability assessment, in particular the technological dimension, compared with the three traditional dimensions. Second, the integration between the sustainability assessment dimensions with the biodiesel supply chain. Third, the relations between the levels of hierarchical structure, that is, each sustainability dimension was assessed by way of a set of principles; likewise, each principles was assessed by a set of criteria and each criterion by a set of indicators. Taking into account the points above, the new framework was comprehensive at both the principle and criteria levels, while also being adaptable to different contexts and biofuel supply chains at the indicator level.

The present research paper also compared the new framework with works about assessment tools for sustainable biofuel production, such as the proposal by (Buytaert et al. 2011; Cucek and Kravanja 2012; FAO and BEFSCI 2012; Silva Lora et al. 2011). These works describe the performance and applicability of an existing selection of tools that are potentially useful for sustainability assessment of bioenergy systems, but do not propose an assessment hierarchical framework.

Another type of sustainability assessments are those conducted on the basis of the life cycle assessment, for example methodology for the PROspective SUstaInability assessment of

Technologies - PROSUITE (Gaasbeek and Meijer 2013), Impact assessment methodology of Leiden University, and Eco-indicator 99 (Goedkoop and Spriensma 2001). These assessment proposals set out impacts categories about social, economic and environmental aspects. The impacts are quantify, and normalized by category and as a result give a sustainability level. The proposed PC&I framework in this work can be strengthen by the assessment methods above mentioned, especially at the level of indicators. In tour, the proposed PC&I framework can contribute the principles and criteria to methodologies based life cycle assessment.

Regarding the conditions for applying the proposed assessment framework, three aspects were identified. First, the advanced biodiesel production assessment should consider the influence of substitute renewable energy production. Second, it must take into account the local climate change influence on the indicator assessment definition. Finally, the third aspect, the adaptation of the framework to a specific context needs a biodiesel production chain stakeholders' participatory consultation to define the set of indicators to be considered. In other regards, when looking at the new framework's structure, in particular the amount of proposed principles and criteria by dimension, it could be underlined that a larger quantity of those were related to principles of environmental and social dimensions (see Figure 14). This fact could be associated with the fact that social, environmental and economic dimensions are traditionally studied in sustainability assessment, such as in Buchholz et al., (2009), Kurka (2013) and Cramer et al., (2007b). In contrast, political and technological dimensions are less linked to sustainability assessments, and in general, the political and technological principles and criteria were associated with economic or social dimensions. In this context, we suggest that further research needs to be undertaken to define a larger set of assessment criteria related to technological and political issues of biodiesel sustainability.

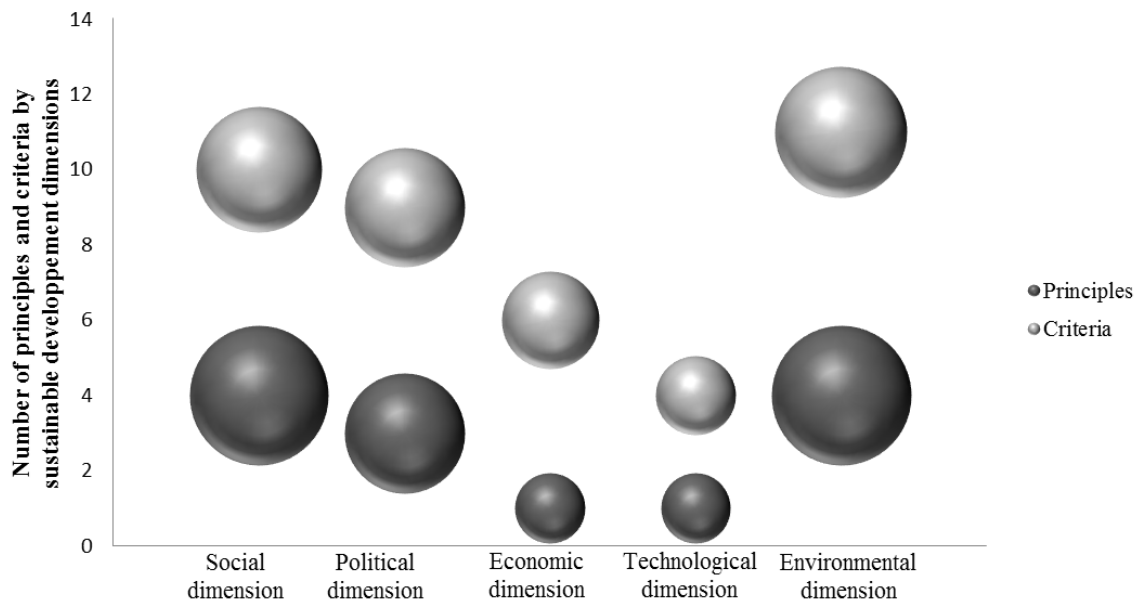


Figure 14. Number of principles and criteria by sustainable development dimensions TBL+

Another point of discussion regarding the state of the art is the manner in which academic and research institutions, as well as governmental and non-governmental institutions, apply the definition of principles and criteria to the environmental sustainability assessment of biodiesel. In general, the social and political criteria do not exemplify or consider the method of quantifying them. In addition, the political criteria do not show the influence of political contexts (macro, meso, and micro) on the sustainability assessment. Also, political and social

criteria as traditionally proposed do not provide tools to analyse the level of reactivity, pro-activity or adaptability that local policies have in regard to recent directives or trends in biodiesel consuming countries. This work considers that the lack of quantification of political and social criteria might make them less comprehensible. Additionally, the difficulty of measuring political and social criteria is quite high due to the lack of formalization of links between the well-being of communities and local and international political policies, as well as economic, environmental and technological criteria.

In the case of the economic and environmental criteria, a relevant point is that these are usually described using measurement units or quantifiable factors. As a weakness of the current frameworks, it was not evident how the economic and environmental criteria are linked with the influence of advanced technologies in biodiesel production or changes in raw materials. Moreover, how the influence of governmental biofuel policies or social acceptability is on the economic and environmental criteria. Regarding the technological criteria, there are criteria associated with the efficiency of transformation processes and the technical feasibility of technologies implemented, but a lack of criteria that link the efficiency and the technical feasibility with the environmental and social impacts of the biodiesel supply chain. Finally, the relationships and influences among stakeholders (socio-technical system approach Greenwell et al. 2012) with the biodiesel supply chain was weakly analysed.

7. Conclusions

There is an unresolved debate on the sustainability of using biodiesel to replace fossil fuel as part of a sustainable development strategy. Some countries continue fostering this industrial sector whereas others are considering reversing this type of initiatives, at least for the first generation of biodiesels.

The biodiesel supply chain is a complex system, as there is a wide range of raw materials determining the supply chain structure, concerned stakeholders, and social or environmental impacts in each country. So this “context dependency” needs comprehensive frameworks integrating all the involved dimensions, but at the same time having the possibility to be adapted to the conditions of each country.

The present paper aims to contribute to the body of knowledge regarding sustainability analysis based on a systematic literature review, and to propose a framework to evaluate the biodiesel supply chain. This framework must then allow decision makers to dispose of more compressive tools to evaluate the sustainability of biodiesel support policies.

In order to do this, a systematic literature review methodology was applied in order to identify relevant documents of this work. Thereafter, a descriptive analysis of the results and the selected documents and their classification was accomplished. Based on these results, a new sustainability assessment framework for biodiesel, named Triple Bottom Line Extended (TBL+), was proposed. Then the application of the new assessment framework was carried out for biodiesel production.

The new proposed framework integrates the biodiesel supply chain, the sustainability dimensions, the principles, the criteria and the indicators. This implies that a hierarchical approach can provide the necessary guidance in understanding and assessing the biodiesel production system.

The biodiesel production sustainability dimensions included in the (TBL+) work were: social, economic, environmental, political and technological. With this proposal, this work aims to strengthen and expand sustainability assessments using a multidimensional view.

The 13 principles and 40 criteria proposed contribute to general sustainability assessment; the next step will be to define a set of indicators for each criterion. The indicators should make it possible to assess a specific context of biodiesel production.

Finally, the principles, criteria an indicator (PC&I) framework consisted of two stages: the first stage was the proposal based on the literature review of the PC&I identification presented in this article. The second stage of the research will validate the PC&I framework by means of expert consultation. It was already performed and answers from 63 international experts on biodiesel were recovered. An article presenting the results of the second stage is currently been prepared.

Nota:

References in Annex 1 but not in article:

(Vaccaro et al. 2010)

(Amigun, Musango, and Brent 2011)

(Timilsina and Shrestha 2011)

(Pruyt and Sitter 2008)

(Cavalett and Ortega 2010)

(E Gnansounou et al. 2009)

(Kim, Kim, and Dale 2009)

(Szarka, Kakucs, and Bezama 2008)

(Gudmundsson 2008)

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Annex 1. Principles, criteria and indicators (PC&I) of sustainability assessment in biodiesel production.

SOCIAL DIMENSION OF SUSTAINABILITY		References
Biomass growers and biodiesel processing companies must:		
PRINCIPLE 1: Respect property rights, land tenure and customary and traditional rights		
CRITERION 1: Respect the rights of land access and land tenure for peasant and indigenous communities.	INDICATOR 1. Indigenous peoples shall control biodiesel management on their lands and territories unless they delegate control with free and informed consent to other agencies.	Edgard Gnansounou, 2011 Vaccaro et al. 2010 Buchholz, Luzadis, et Volk 2009 FSC, Forest Stewardship Council GBEP, Global Bioenergy Partnership SAN/RA, Sustainable Agriculture Network/Rain forest Alliance Interamerican Development Bank- Sustainability Scorecard PEFC, Program for the Endorsement of Forest Certification schemes RTRS, Roundtable for Responsible Soy Production Nordic Ecolabelling of Fuels RSB, Roundtable on Sustainable Biofuels RSPO, Roundtable on Sustainable Palm Oil SBA, Sustainable Biodiesel Alliance RTFO, Renewable Transport Fuel Obligation – UK Directive 2009/28/EC of the European Union
CRITERION 2: Promote the minimization of conflicts over the use, access and land tenure.	INDICATOR 2. Biodiesel management shall not threaten or diminish, directly or indirectly, either the resources or tenure rights of indigenous peoples.	
	INDICATOR 3. Sites of special cultural, ecological, economic or religious significance to indigenous peoples shall be clearly identified in cooperation with such peoples, and recognized and protected by biodiesel managers.	
	INDICATOR 4. Promotion of the involvement of stakeholders about use of land, management of conflicts and tenure of land.	
	INDICATOR 5. Avoidance of land tenure conflicts.	
	INDICATOR 6. Projects should not exclude poor people from the land in order to avoid leakage effects.	
	INDICATOR 7. Land ownership should be equitable.	
	INDICATOR 8. Number of rights granted by constitutions, regulations and official tribunals or other laws: customary, casual, temporary and secondary.	
	INDICATOR 9. Number of people in a population with safe titles (for example, registered) in relation to the number of people with insecure titles on the land, in the area of direct influence of the plantations of palm oil and biodiesel processing.	
Biodiesel supply chain must:		
PRINCIPLE 2: Be socially acceptable		
CRITERION 3: contribute to national energy security and the access of rural communities to energy.	INDICATOR 10. Index of energy matrix diversification.	(Musango et al. 2011) (Amigun, Musango, et Brent 2011) (Musango et al. 2012) (Edgard Gnansounou 2011) (Markevicius et al. 2010) (Kurka et Blackwood 2013) FSC, Forest Stewardship Council SAI, Social Accountability International IFOAM, International Federation of Organic Agriculture Movements RTRS, Roundtable for Responsible Soy Production UNEP, 2009. Towards Sustainable Production RSB, Roundtable on Sustainable Biofuels RSPO, Roundtable on Sustainable Palm Oil SBA, Sustainable Biodiesel Alliance RTFO, Renewable Transport Fuel Obligation – UK Social Fuel seal – Brazil
CRITERION 4: To prevent generation of environmental noise.	INDICATOR 11. Government Investment in electricity infrastructure.	
CRITERION 5: To prevent changes in landscape generating undesirable visual impact for communities.	INDICATOR 12. Qualitative indicator scale of 1 to 5, 1 being the lower noise impact and 5, a significant noise impact.	
CRITERION 6: To contribute to local prosperity associated with the reduction of poverty and the promotion of human rights.	INDICATOR 13. Qualitative indicator scale of 1 to 5, 1 being the lower visual impact and 5, a significant visual impact.	
	INDICATOR 14. Stakeholder involvement in the decisions that concern them	
	INDICATOR 15. Total annual national of households without access to public services of the total number of families, in the direct area influence of oil palm plantations and mining and transformation plants of biodiesel	
	INDICATOR 16. Access to health care and medication	
	INDICATOR 17. Total annual national of Illiteracy people aged 15 or more of the total number of persons, in the direct influence of oil palm plantations and mining and transformation plants of biodiesel.	
	INDICATOR 18. Opportunities for employment: Total annual number of employment in plantation of biomass, extraction and transformation plant.	
	INDICATOR 19. Total annual national of head of household's opinion about better living standards of their home, which was about 5 years ago of the total number of families, in the direct area influence of oil palm plantations and mining and processing plants of biodiesel.	
	INDICATOR 20. Unsatisfied basic needs: Weighted average of the annual percentages of people in poverty, according to the indicator of unmet basic needs in the municipalities that are part of the zone of influence of the biodiesel production chain.	
	INDICATOR 21. Number of organizations of the community partition in biodiesel production chain per year.	
	INDICATOR 22. Participation of small farmers (less than 20 ha): Number of small farmers of palm oil for biodiesel per number total farmers of palm oil for biodiesel.	
INDICATOR 23. Land prices of a hectare of land with palm oil for biodiesel in areas influenced by the production of biodiesel per year.		
INDICATOR 24. Total national of people displacement from areas affected by the number of persons received by displacement from other areas in the direct influence of oil palm plantations and mining and processing plants of biodiesel.		

SOCIAL DIMENSION OF SUSTAINABILITY		References
	INDICATOR 25. Total national estimated annual lands usurped hectares in areas of direct influence of the biodiesel production chain.	
	INDICATOR 26. Annual amount of conflict associated with guerrilla groups, drug trafficking, or common criminals who present in the direct influence of oil palm plantations and mining and processing plants of biodiesel.	
Biodiesel supply chain must:		
PRINCIPLE 3: Promote responsible work conditions through all their activities		
CRITERION 7: ensure that all their activities are carried out protecting health and promoting safety for employees.	INDICATOR 27. The Process Route Healthiness Index (PRHI)	(Halog et Manik 2011) Edgard Gnansounou 2011) (Buchholz, Luzadis, et Volk 2009) NTA 8080, Sustainable Production of Biomass—The Netherlands CSBP, Council on Sustainable Biomass Production, the United States. ACCS, Assured Combinable Crops Scheme SAI, Social Accountability International Sustainability Guide in Biomass Production and Processing in the Biofuel chain in Colombia ISO 26000 – Responsibility social. GBEP, Global Bioenergy Partnership ISCC, International Sustainability and Carbon Certification SAN/RA, Sustainable Agriculture Network/Rain forest Alliance Bonsucro, Better Sugarcane Initiative FLO, Fairtrade Labelling Organizations International PEFC, Program for the Endorsement of Forest Certification schemes RTRS, Roundtable for Responsible Soy Production RSB, Roundtable on Sustainable Biofuels RSPO, Roundtable on Sustainable Palm Oil SBA, Sustainable Biodiesel Alliance RFS2, Renewable Fuel Standard, the United States,2010 RTFO, Renewable Transport Fuel Obligation – UK Directive 2009/28/EC of the European Union LCFS, Low Carbon Fuel Standard (LCFS), California, United States. Interamerican Development Bank- Sustainability Scorecard
	INDICATOR 28. Affiliation of the employees to occupational hazards insurance	
	INDICATOR 29. Hazardous Materials Protection: Employer provides and employees use adequate protective clothing, appropriate safety equipment, and filtered air respirator systems and/or positive pressure cabs for workers handling highly toxic chemicals.	
	INDICATOR 30. Number of work accidents and occupational sicknesses in the different stages of the biodiesel production chain	
	INDICATOR 31. Sanitation: Employer provides clean drinking water and clean latrines with hand-washing stations to workers.	
	INDICATOR 32. Insurance against workplace injury: Employer provides workers compensation and disability insurance for all full time employees.	
	INDICATOR 33. Environmental training of employees, Job instructions, on the job training	
INDICATOR 34. Fair Treatment of Workers		
CRITERION 8: To guarantee the respect of labor laws (associated with forced child labor, discrimination, disciplinary practices, working hours, salaries, incidence of occupational accidents, illnesses and deaths, forced and compulsory labor, and unions).	INDICATOR 35. Number of workers with direct labor contracts with enterprises	
	INDICATOR 36. Number of workers employed through other forms of recruitment (associations, intermediary companies).	
	INDICATOR 37. Number of workers who belong to trade unions	
	INDICATOR 38. Number of workers under 18 years of age	
Biomass cultivation and production of biodiesel must:		
PRINCIPLE 4: Prevent alteration to food supply or other local uses of biomass (e.g. energy production, as medicine raw material and as building material)		
CRITERION 9: To prevent alteration to trade and food supply at the local level.	INDICATOR 39. The consumer price index (CPI) measures changes over time in the general level of prices of consumer goods and services that households acquire, use or pay for consumption.	FAO 2012) (Oviedo et al. 2011) (Timilsina et Shrestha 2011) (Pruyt et Sitter 2008) (Buchholz, Luzadis, et Volk 2009) (Markevičius et al. 2010) (Kurka et Blackwood 2013) GBEP, Global Bioenergy Partnership Interamerican Development Bank- Sustainability Scorecard NTA 8080, Sustainable Production of Biomass—The Netherlands CSBP, Council on Sustainable Biomass Production, the United States. GAP, Global Partnership for Good Agricultural Practice IFOAM, International
	INDICATOR 40. Undernourishment: Proportion of undernourished in the population (%). Annual number of undernourished people in the total population of the country	
	INDICATOR 41. Amount of hectare of agricultural land and Livestock Research in active production relative to total land available with this vocation, per year.	
	INDICATOR 42. Vulnerability Analysis and Mapping VAM, is network of food security experts who work closely with national governments, UN partners and NGOs to inform food insecurity and hunger related programs and policies.	Federation of Organic Agriculture Movements Sustainability Guide in Biomass Production and Processing in the Biofuel chain in Colombia RTRS, Roundtable for Responsible Soy Production UNCTAD Biofuels Initiative RSB, Roundtable on Sustainable Biofuels RSPO, Roundtable on Sustainable Palm Oil RTFO, Renewable Transport Fuel Obligation – UK Social Fuel seal – Brazil Directive 2009/28/EC of the European Union Food security information network. http://www.fsincop.net/resource-centre/detail/en/c/178639/
CRITERION 10: To prevent alteration to biomass production for traditional local uses other than biodiesel (e.g. energy production, as medicine raw material and as building material).		

POLITICAL DIMENSION OF SUSTAINABILITY		References
PRINCIPLE 5: National promotion policies for the production and consumption of first generation biodiesel must be in accordance with international policies.		
CRITERION 11: Level of agreement between the amount of biodiesel produced domestically under a subsidy scheme and the one produced internationally under similar schemes.	INDICATOR 43. Amount of USD incentive or tax in previous year less the incentive or tax in the current year with relationship the incentive or tax in the current year	(Musango et al. 2012) (Edgard Gnansounou 2011)
	INDICATOR 44. Local price in USD of biodiesel in a scheme of biofuel price controls.	(Vaccaro et al. 2010)

POLITICAL DIMENSION OF SUSTAINABILITY		References
CRITERION 12: Level of agreement between domestic "1st-gen./advanced" biodiesel production ratio.	INDICATOR 45. (production of first generation biodiesel)/(production of advanced biodiesel) and international "1st-gen./advanced" ratios	(Franco et Flórez 2009) (Timilsina et Shrestha 2011)
CRITERION 13: Level of agreement between the percentages of national biodiesel blend - diesel and percentages of international blend.	INDICATOR 46. The percentages of national biodiesel blend - diesel and percentages of international blend.	(Bantz et Deaton 2006) (Zapata, Franco, et Dyner 2011)
CRITERION 14: Level of national capability in biodiesel research and development (first generation and advanced) regarding international capabilities.	INDICATOR 47. Fiscal costs of the implementation of the biodiesel promotion policy INDICATOR 48. Research and development expenditure (% of GDP)	(Markevicius et al. 2010) (Kurka et Blackwood 2013)
PRINCIPLE 6. National policies related to the promotion of biodiesel production should be consistent with international environmental policies on acceptable forms of biomass, suitable land for the cultivation of biomass and allowed thresholds of greenhouse gas emissions in the life cycle of biodiesel		
CRITERION 15: Amount of biomass produced domestically in compliance with international standards (type of biomass that does not compete with food).	INDICATOR 49. Annual amount of raw material for the production of biodiesel produced compliance with the criteria of renewable biomass	FSC, Forest Stewardship Council NTA 8080, Sustainable Production of Biomass—The Netherlands CSBP, Council on Sustainable Biomass Production, the United States.
CRITERION 16: National amount of land used for growing biomass for biodiesel production that meets the international requirements of land suitable for use (i.e. those that do not come from direct exchange of primary forests, exclusion areas with high biodiversity value, land with high carbon stocks and ecologically sensitive areas declared as protected).	INDICATOR 50. Amount of biodiesel produced under voluntary certification criteria (e.g. RSP0, ISCC, NTA 8080) relative to the total amount of biodiesel produced globally.	Sustainability Guide in Biomass Production and Processing in the Biofuel chain in Colombia ISO 26000 – Responsibility social. ISCC, International Sustainability and Carbon Certification Interamerican Development Bank- Sustainability Scorecard PEFC, Program for the Endorsement of Forest Certification schemes RTRS, Roundtable for Responsible Soy Production RFS2 United States (EPA 2010)
CRITERION 17: Amount of domestically produced biodiesel that meets international policy on minimum average or threshold of greenhouse gas emissions in their life cycle, including indirect changes in land use.	INDICATOR 51. Total global consumed tons of 1st generation biodiesel that are permitted by international policies	BLE, Sustainable Biomass Production. Germany RSB, Roundtable on Sustainable Biofuels RSPO, Roundtable on Sustainable Palm Oil Directive 2009/28/EC of the European Union FLO, Fairtrade Labelling Organizations International
PRINCIPLE 7. The actors involved in biodiesel's production chain should promote commitment to ethics, transparency and compliance with local laws		
CRITERION 18: Level of perception of the local community about the degree of ethical commitment by the actors in biodiesel's production chain.	INDICATOR 52. Define and communicate the standards of ethical behavior in the organization	RTRS, Roundtable for Responsible Soy Production RFS2 United States (EPA 2010) BLE, Sustainable Biomass Production. Germany RSB, Roundtable on Sustainable Biofuels RSPO, Roundtable on Sustainable Palm Oil RTFO, Renewable Transport Fuel Obligation – UK Directive 2009/28/EC of the European Union BLCAO, Biofuels life cycle assessment ordinance Swiss Confederation LCFS, Low Carbon Fuel Standard (LCFS), California, United States.
	INDICATOR 53. Have you notified the relevant authorities, where appropriate, and completed an Environmental Impact Assessment (EIA)	
INDICATOR 54. Reporte de multas por incumplimiento legal en temas laborales, impuestos, ambientales, entre otros.		
INDICATOR 55. Awareness of responsibilities, according to applicable laws (environmental, fiscal, social and labor) can be demonstrated.		
INDICATOR 56. Adopt and implement the standards of ethical behavior. Establish mechanisms for monitoring and verification.		
CRITERION 19: Level of perception of the local community about the commitment to transparency and compliance with local laws by the actors involved in biodiesel's production chain.	INDICATOR 57. The organization must be transparent in its activities, which makes control over them, how to be making the decisions, and how their functions are defined.	
	INDICATOR 58. The organization must be clear about the source of funds for their activities	
	INDICATOR 59. The organization must know the likely effects of their decisions on stakeholders, society, economy and environment.	
	INDICATOR 60. The organization inform to consumers about the environmental effects of products they are consuming and to raise environmental standards in the manufacturing of specific products	
	INDICATOR 61. Production of any Genetically Modified Organisms must comply with legal requirements.	

ECONOMIC DIMENSION OF SUSTAINABILITY	References
PRINCIPLE 8. Biodiesel production must be sustainable at both macroeconomic and microeconomic level	FSC, Forest Stewardship Council UNCTAD Biofuels Initiative

ECONOMIC DIMENSION OF SUSTAINABILITY		References
CRITERION 20: Level of influence (international and domestic) of reserves, production, consumption and prices for oil on the production of first generation biodiesel.	INDICATOR 62. Global Petroleum reserves per year and per global ton of first generation biodiesel produced	(Oviedo et al. 2011)
	INDICATOR 63. Global Petroleum production per year and biodiesel per global ton of first generation biodiesel produced	
	INDICATOR 64. Global annual Petroleum consumption per global ton of first generation biodiesel produced	
	INDICATOR 65. Global annual Prices of petroleum per global ton of first generation biodiesel produced	
	INDICATOR 66. Local annual Petroleum reserves per local ton of first generation biodiesel produced	
	INDICATOR 67. Local annual Petroleum production per local ton of first generation biodiesel produced	
	INDICATOR 68. Local annual Petroleum consumption per local ton of first generation biodiesel produced	
	INDICATOR 69. Local annual Prices of petroleum per local ton of first generation biodiesel produced	
	CRITERION 21: Level of influence (international and domestic) of production, consumption and prices for diesel on the production of first generation biodiesel.	
INDICATOR 71. Global annual consumption quantity of diesel per global ton of first generation biodiesel produced		
INDICATOR 72. Global annual prices of diesel per global ton of first generation biodiesel produced		
INDICATOR 73. Local annual production quantity of diesel per local ton of first generation biodiesel produced		
INDICATOR 74. Local annual consumption quantity of diesel per local ton of first generation biodiesel produced		
INDICATOR 75. Local annual prices of diesel per local ton of first generation biodiesel produced		
INDICATOR 76. Local annual quantity of Vehicle diesel per local ton of first generation biodiesel produced		
CRITERION 22: Annual production (international and domestic) of first generation biodiesel.	INDICATOR 77. Global annual production quantity of biodiesel 1 ^a generation	(Musango et al. 2011) (Musango et al. 2012) (Edgard Gnansounou 2011) (Wang, Calderon, et Lu 2011) (Oviedo et al. 2011) (Franco et Flórez 2009) (Timilsina et Shrestha 2011) (Bantz et Deaton 2006) (Wang, Calderon, et Lu 2011) (Zapata, Franco, et Dyer 2011) (Kurka et Blackwood 2013)
	INDICATOR 78. Global annual consumption quantity of biodiesel 1 ^a generation per global ton of first generation biodiesel produced	
	INDICATOR 79. Global annual prices of biodiesel 1 ^a generation per global ton of first generation biodiesel produced	
	INDICATOR 80. Local annual production quantity of biodiesel 1 ^a generation	
	INDICATOR 81. Local annual consumption quantity of biodiesel 1 ^a generation per local ton of first generation biodiesel produced	
	INDICATOR 82. Local annual prices of biodiesel 1 ^a generation per local ton of first generation biodiesel produced	
	INDICATOR 83. Local production capacity of the 1st generation biodiesel per local ton of first generation biodiesel produced	
	INDICATOR 84. Local profitability of production of biodiesel 1a generation per local ton of first generation biodiesel produced	
	INDICATOR 85. Annual balance energy costs in the biodiesel production per local ton of first generation biodiesel produced	
	INDICATOR 86. Annual operational and pollution control cost in the biodiesel production per local ton of first generation biodiesel produced	
CRITERION 23: Level of influence of production, consumption and prices (international and domestic) for vegetable oil on the production of first generation biodiesel.	INDICATOR 87. Global annual prices of palm oil per global ton of first generation biodiesel produced	
	INDICATOR 88. Global total annual production of palm oil per global ton of first generation biodiesel produced	
	INDICATOR 89. Global annual consumption for palm oil for production of biodiesel per global ton of first generation biodiesel produced	
	INDICATOR 90. Global annual consumption for palm oil in different uses to biodiesel per global ton of first generation biodiesel produced	
	INDICATOR 91. Local annual prices of palm oil per local ton of first generation biodiesel produced	
	INDICATOR 92. Local total annual production of palm oil per local ton of first generation biodiesel produced	
	INDICATOR 93. Local annual consumption for palm oil for production of biodiesel per local ton of first generation biodiesel produced	
	INDICATOR 94. Local annual consumption for palm oil for human consumption per local ton of first generation biodiesel produced	
	INDICATOR 95. Aboveground net primary productivity (at the stage of cultivation of oil palm) biodiesel per annual local ton of first generation biodiesel produced. Taking into account the effects of climate change	
CRITERION 24: Level of influence of production, consumption and prices (international and domestic) for glycerin on the production of first generation biodiesel.	INDICATOR 96. Local annual price of byproduct glycerin per local ton of first generation biodiesel produced	
	INDICATOR 97. Local annual production of byproduct glycerin biodiesel per local ton of first generation biodiesel produced	
	INDICATOR 98. Local annual consumption of byproduct glycerin biodiesel per local ton of first generation biodiesel produced.	
CRITERION 25: Level of influence of production, consumption and prices (international and domestic) for advanced biodiesel on first generation biodiesel.	INDICATOR 98. Global annual prices of advanced biodiesel per global ton of first generation biodiesel produced	(Kurka et Blackwood 2013) UNCTAD Biofuels Initiative
	INDICATOR 99. Global annual production of advanced biodiesel per global ton of first generation biodiesel produced	
	INDICATOR 100. Global annual consumption of advanced biodiesel per global ton of first generation biodiesel produced	

TECHNOLOGICAL DIMENSION OF SUSTAINABILITY		References
PRINCIPLE 9. Technology used in the biodiesel supply chain should promote the reduction of negative impacts on the environment, efficiency and cost reduction in processes over time		
CRITERION 26: Level of influence of production (international and domestic) of advanced biodiesel from non-edible feedstock on demand (international and domestic) of soil and water resources.	INDICATOR 101. Amount of hectares of land required for the production of raw materials for advanced biodiesel or second and third generation.	(Musango et Brent 2011) (Brent et Musango 2013) (Vaccaro et al. 2010) (Timilsina et Shrestha 2011)
	INDICATOR 103. Amount of water required for the production of raw materials and advanced biodiesel or second and third generation transformation.	

TECHNOLOGICAL DIMENSION OF SUSTAINABILITY		References
CRITERION 27: Level of influence of global and domestic production of advanced biodiesel based on non-conventional technologies on efficiency of processes and cost reduction.	INDICATOR 104. Reduction of production costs dependent on the production of advanced biodiesel technology apprenticeship	(Bantz et Deaton 2006) (Kurka et Blackwood 2013) GBEP, Global Bioenergy Partnership UNCTAD Biofuels Initiative UNEP, 2009. Towards Sustainable Production RSB, Roundtable on Sustainable Biofuels
CRITERION 28: Level of influence of technology trends for engines on the production of first generation biodiesel.	INDICATOR 105. Demand for biodiesel according to the number of vehicles that do not use liquid fuels.	
CRITERION 29. Level of influence of technological learning (global and domestic) in the production of first generation biodiesel on reducing costs over time	INDICATOR 106. Reducing costs of production by independent of production technological learning (associated with technological maturity that can be assessed indirectly by scientific articles and patents advanced biodiesel or second and third generation)	

ENVIRONMENTAL DIMENSION OF SUSTAINABILITY		References
The actors involved in the biodiesel supply chain must:		
PRINCIPLE 10. Ensure their activities maintain or improve the air, soil and water quality, as well as they do a proper management of solid waste and wastewater		
CRITERION 30: To ensure that <u>air quality</u> is maintained or improved.	INDICATOR 107. Annual tons of nitrogen oxide gas emissions engine transport vehicles using biodiesel fuel blends (in the national capital).	(Edgard Gnansounou 2011) (Timilsina et Shrestha 2011) (McBride et al. 2011) (Kurka et Blackwood 2013) ISO 14040 - Life Cycle Assessment GBEP, Global Bioenergy Partnership LCFS, Low Carbon Fuel Standard (LCFS), California, United States. ISO 26000 – Responsibility social. Bonsucro, Better Sugarcane Initiative
	INDICATOR 108. Annual tons of particulate matter gas emissions engine transport vehicles using biodiesel fuel blends (in the national capital)	
	INDICATOR 109. Annual tons of carbon monoxide gas emissions engine transport vehicles using biodiesel fuel blends (in the national capital)	
	INDICATOR 110. Annual tons of total hydrocarbons gas emissions engine transport vehicles using biodiesel fuel blends (in the national capital)	
	INDICATOR 111. Annual tons of total atmospheric acidification burden per unit mass, environmental burden is kg Sulphur dioxide equivalent product (in the national capital)	
	INDICATOR 112. Annual tons of total of persistent organic pollutants (POPs) and substances that deplete the ozone layer (in the national capital)	
CRITERION 31: To promote the <u>efficient use of water</u> to minimize pressure on the local availability of the resource.	INDICATOR 113. Average cubic meters of water available per year in direct area of influence of biodiesel production chain (taking into account the effects of climate change)	(BID et MMEC 2012) (FAO 2012) (Musango et al. 2011) (Edgard Gnansounou 2011) (Kurka et Blackwood 2013) CSBP, Council on Sustainable Biomass Production, the United States. ISO 14040 - Life Cycle Assessment GBEP, Global Bioenergy Partnership SAN/RA, Sustainable Agriculture Network/Rain forest Alliance Interamerican Development Bank- Sustainability Scorecard Bonsucro, Better Sugarcane Initiative RTRS, Roundtable for Responsible Soy Production GGLS2, Green Gold Label 2.
	INDICATOR 114. Index linking shortage of water available (m3) with respect to water consumption (m3) in direct area of influence of biodiesel production chain	
	INDICATOR 115. Water used in m3 by hectare of palm oil cultivation for biodiesel per year	
	INDICATOR 116. Water used annually in m3 for production of one ton of biodiesel in the step of transformation with in productive chain.	
	INDICATOR 117. Annual quantity of water utilized or recycled of the total water utilized in the biodiesel production.	
	INDICATOR 118. Annual ratio of the amount (m3) of water used for growing biomass and biodiesel production of all water used for human consumption and food crops in the area of direct influence (taking into account the effects of climate change)	
CRITERION 32: To minimize the generation of contaminated effluents and treat such effluents in order to maintain or improve the <u>local water quality</u>	INDICATOR 119. Concentration annual average (mg/l) of suspended sediment in the principal stream (those that are used for human consumption) that are part of the direct influence area (watershed) of oil palm plantations.	(BID et MMEC 2012) (Edgard Gnansounou 2011) (Kurka et Blackwood 2013) NTA 8080, Sustainable Production of Biomass—The Netherlands CSBP, Council on Sustainable Biomass Production, the United States. ISO 14040 - Life Cycle Assessment GBEP, Global Bioenergy Partnership ISCC, International Sustainability and Carbon Certification SAN/RA, Sustainable Agriculture Network/Rain forest Alliance
	INDICATOR 120. Concentration annual average (mg/l) of phosphorus (P) in the principal stream (those that are used for human consumption) that are part of the direct influence area (watershed) of oil palm plantations.	
	INDICATOR 121. Concentration annual average (mg/l) of nitrogen in the principal stream (those that are used for human consumption) that are part of the direct influence area (watershed) of oil palm plantations.	
	INDICATOR 122. Concentration annual average (mg/l) of herbicide concentration in the principal stream (those that are used for human consumption) that are part of the direct influence area (watershed) of oil palm plantations.	
		GGLS2, Green Gold Label 2. Agriculture Source Criteria Nordic Ecolabelling of Fuels UNEP, 2009. Towards Sustainable Production RSB, Roundtable on Sustainable Biofuels RSPO, Roundtable on Sustainable Palm Oil SBA, Sustainable Biodiesel Alliance RTFO, Renewable Transport Fuel Obligation – UK Directive 2009/28/EC of the European Union BLCAO, Biofuels life cycle assessment ordinance Swiss Confederation BioNa Dv, Biomass Sustainability order, Germany

ENVIRONMENTAL DIMENSION OF SUSTAINABILITY		References	
	INDICATOR 123. Discharge rate (m3/year) of wastewater generated in the production of one ton of biodiesel in transformation industry per year	Interamerican Development Bank-Sustainability Scorecard RTRS, Roundtable for Responsible Soy Production	BioNa Dv, Biomass Sustainability order, Germany
	INDICATOR 124. Discharge in kg of nitrate per fresh fruit bunch in oil plantation biodiesel per year		
	INDICATOR 125. Discharge in kg of phosphorus per fresh fruit bunch in oil plantation biodiesel by year		
CRITERION 33: To ensure that <u>non-hazardous and hazardous wastes</u> are managed responsibly (collection, storage, transportation, treatment and/or disposal) by promoting their minimization, reuse and/or recycling.	INDICATOR 126. Amount in tons of hazardous waste taken to a proper final disposal of all waste generated in the stages of cultivation, oil extraction and transformation into biodiesel per year.	(BID et MMEC 2012) (Buchholz, Luzadis, et Volk 2009) FSC, Forest Stewardship Council NTA 8080, Sustainable Production of Biomass—The Netherlands GAP, Global Partnership for Good Agricultural Practice IFOAM, International Federation of Organic Agriculture Movements Sustainability Guide in Biomass Production and Processing in the Biofuel chain in Colombia ISO 14040 - Life Cycle Assesment ISCC, International Sustainability and Carbon Certification SAN/RA, Sustainable Agriculture Network/Rain forest Alliance Interamerican Development Bank-Sustainability Scorecard	GQA, Genesis Quality Assurance RTRS, Roundtable for Responsible Soy Production GGLS2, Green Gold Label 2. Agriculture Source Criteria Nordic Ecolabelling of Fuels RSB, Roundtable on Sustainable Biofuels RSPO, Roundtable on Sustainable Palm Oil SBA, Sustainable Biodiesel Alliance RFS2, Renewable Fuel Standard, the United States, 2010 RTFO, Renewable Transport Fuel Obligation – UK Directive 2009/28/EC of the European Union BLCAO, Biofuels life cycle assessment ordinance Swiss Confederation Bonsucro, Better Sugarcane Initiative
	INDICATOR 127. Amount in tons of waste are reuse or recycle with relation of total waste generated in the stages of cultivation of palm oil per year.		
	INDICATOR 128. Amount in tons of waste are recovered or valued with relation of total waste generated in the stages of transformation of oil palm to biodiesel		
	INDICATOR 129. Total amount of non-hazardous waste generated annually per ton of biodiesel produced		
CRITERION 34: The biomass cultivation activities for biodiesel must maintain or improve the <u>soil quality</u> (physical, chemical and biological properties) by establishing responsible practices of crop management, handling of agrochemicals and pest control.	INDICATOR 130. Amount in mg of total organic carbon (TOC) measured annually in a hectare of oil palm cultivation	(FAO 2012) (Musango et al. 2012) (Edgard Gnansounou 2011) (McBride et al. 2011) NTA 8080, Sustainable Production of Biomass—The Netherlands CSBP, Council on Sustainable Biomass Production, the United States. ACCS, Assured Combinable Crops Scheme GAP, Global Partnership for Good Agricultural Practice IFOAM, International Federation of Organic Agriculture Movements LEAF, Linking Environment and Farming GBEP, Global Bioenergy Partnership ISCC, International Sustainability and Carbon Certification SAN/RA, Sustainable Agriculture Network/Rain forest Alliance	Interamerican Development Bank-Sustainability Scorecard Bonsucro, Better Sugarcane Initiative GQA, Genesis Quality Assurance RTRS, Roundtable for Responsible Soy Production GGLS2, Green Gold Label 2. Agriculture Source Criteria RSB, Roundtable on Sustainable Biofuels RSPO, Roundtable on Sustainable Palm Oil SBA, Sustainable Biodiesel Alliance RTFO, Renewable Transport Fuel Obligation – UK Social Fuel seal – Brazil Directive 2009/28/EC of the European Union BLCAO, Biofuels life cycle assessment ordinance Swiss Confederation BioNa Dv, Biomass Sustainability order, Germany
	INDICATOR 131. Amount in mg of total nitrogen measured annually in a hectare of oil palm cultivation		
	INDICATOR 132. Amount in mg of extractable phosphorus measured annually in a hectare of oil palm cultivation		
	INDICATOR 133. Annual measure of bulk density in soils in g/cm3 used for growing oil palm		
	INDICATOR 134. Amount in tons of agrochemical (fertilizers minerals or organics and pesticides) used per hectare of cultivation of palm oil. In special, the agrochemicals prohibited in the Stockholm and Rotterdam Conventions		
	INDICATOR 135. Quantity annual of land, in region with influence of oil palm cultivation for biodiesel, those are degraded due to acidification and the salinization.		
	INDICATOR 136. Quantity (hectares per year) of eroded land in the direct influence of the production of biodiesel		
	INDICATOR 137. Existence of crop rotation plan / cycle. This plan will identify annual cropping for current year and the intentions for the future (over three years).		
PRINCIPLE 11. Biodiesel supply chain must have a positive balance of greenhouse gases, and maintain or promote carbon sinks			
CRITERION 35: The amount of <u>greenhouse gases</u> captured or stored in carbon sinks (biomass associated) must be greater than the amount of greenhouse gases emitted by the biodiesel supply chain.	INDICATOR 138. Ton equivalent CO2 emitted by direct change of use of one hectare of land, multiplied by the total annual number of hectares that suffered a direct change in the land use in the area of direct influence of the biodiesel production chain.	(BID et MMEC 2012) (FAO 2012) (Musango et al. 2011) (Musango et al. 2012) (Edgard Gnansounou 2011) (E Gnansounou et al. 2009) (Wang, Calderon, et Lu 2011) (Oviedo et al. 2011) (Kim, Kim, et Dale 2009) (Timilsina et Shrestha 2011) (Szarka, Kakucs, et Bezama 2008) (Wang, Calderon, et Lu 2011) (McBride et al. 2011)	GBEP, Global Bioenergy Partnership ISCC, International Sustainability and Carbon Certification GGLS2, Green Gold Label 2. Agriculture Source Criteria UNCTAD Biofuels Initiative UNEP, 2009. Towards Sustainable Production RTFC, Renewable Transport Fuel Certificates, UK BLE, Sustainable Biomass Production. Germany RSB, Roundtable on Sustainable Biofuels
	INDICATOR 139. Generated tons of nitrogen oxide associated with the use of chemical fertilizers and pest control on a hectare of palm oil for biodiesel production.		
	INDICATOR 140. Ton annual equivalent CO2 emitted by the extraction of oil and transformation plants of biodiesel in the production of one ton of biodiesel		

ENVIRONMENTAL DIMENSION OF SUSTAINABILITY		References	
	<p>INDICATOR 141. Annual tons of CO2 equivalent emitted by vehicle engines to use biodiesel in relation to the total annual tons of biodiesel consumed in the transport sector</p> <p>INDICATOR 142. Ton equivalent CO2 emitted annually by indirect change of use of one hectare of land, multiplied by the total annual number of hectares that suffered an indirect change in the land use in the area of direct influence of the biodiesel production chain</p> <p>INDICATOR 143. Ton equivalent CO2 emitted by activities of logistic chain relationship with of biodiesel production chain per ton of biodiesel produced.</p> <p>INDICATOR 144. Ton of CO2 equivalent annually captured or maintained in carbon sinks</p>	<p>(Gudmundsson 2012) (Buchholz, Luzadis, et Volk 2009) (Kurka et Blackwood 2013) NTA 8080, Sustainable Production of Biomass—The Netherlands CSBP, Council on Sustainable Biomass Production, the United States. Sustainability Guide in Biomass Production and Processing in the Biofuel chain in Colombia ISO 14040 - Life Cycle Assessment Bonsucro, Better Sugarcane Initiative RTRS, Roundtable for Responsible Soy Production RFS2 United States (EPA 2010)</p> <p>RSPO, Roundtable on Sustainable Palm Oil SBA, Sustainable Biodiesel Alliance RFS2, Renewable Fuel Standard, the United States, 2010 RTFO, Renewable Transport Fuel Obligation – UK Directive 2009/28/EC of the European Union BLCAO, Biofuels life cycle assessment ordinance Swiss Confederation BioNa Dv, Biomass Sustainability order, Germany LCFS, Low Carbon Fuel Standard (LCFS), California, United States.</p>	
PRINCIPLE 12. Biodiesel supply chain must promote the conservation and protection of biodiversity and wildlife.			
<p>CRITERION 36: Transformation of natural ecosystems and loss of native natural landscape should be avoided during biomass cultivation and biodiesel production.</p> <p>CRITERION 37: Biodiesel supply chain must preserve areas with fragile ecosystems (both terrestrial and aquatic ecosystems) such as nature reserves defined by the national environmental legislation.</p> <p>CRITERION 38: The number of species of wildlife listed as vulnerable or endangered should not be affected during biomass cultivation and processing of biodiesel.</p>	<p>INDICATOR 145. Land used (ha/year) for foods crops different to palm oil cultivation for biodiesel.</p> <p>INDICATOR 146. Amount annual of hectare land used for palm oil crop to be transformed in biodiesel</p> <p>INDICATOR 147. Conexant index Equivalent Area (ACE) for evaluating the connectivity ecosystem</p> <p>INDICATOR 148. Annual amount of biodiversity projects and promotion of local traditional knowledge, with the participation of communities</p> <p>INDICATOR 149. Annual amount of degraded land (e.g. erosion, salinization, acidification, or other causes) and areas of natural cover change, in areas directly affected by oil palm plantations or processors biodiesel.</p> <p>INDICATOR 150. Amount of land (ha) used for forests and natural ecosystems in direct area of influence of palm oil plantation and biodiesel transformation plant, per year</p> <p>INDICATOR 151. Average annual temperature of aquatic ecosystems (e.g. estuaries, rivers, lakes, wetlands) located in the area of direct influence of the oil palm plantations and transformation of biodiesel.</p> <p>INDICATOR 152. Aquatic oxygen demand of aquatic ecosystems (e.g. estuaries, rivers, lakes, wetlands) located in the area of direct influence of the oil palm plantations and transformation of biodiesel.</p> <p>INDICATOR 153. Number annual of species of fauna and flora, specifically those who are in danger or are considered of special conservation interest, for The International Union for Conservation of Nature (IUCN) and local research organizations.</p> <p>INDICATOR 154. Areas established as wildlife reserves (e.g. national parks, reserves civil society or private reserve areas) located in the area of direct influence of the oil palm plantations and plants</p>	<p>(FAO 2012) (Edgard Gnansounou 2011) (Groom, Gray, et Townsend 2008) (Timilsina et Shrestha 2011) (McBride et al. 2011) (Buchholz, Luzadis, et Volk 2009) (Markevičius et al. 2010) FSC, Forest Stewardship Council NTA 8080, Sustainable Production of Biomass—The Netherlands CSBP, Council on Sustainable Biomass Production, the United States. ACCS, Assured Combinable Crops Scheme LEAF, Linking Environment and Farming Sustainability Guide in Biomass Production and Processing in the Biofuel chain in Colombia ISO 14040 - Life Cycle Assessment Interamerican Development Bank-Sustainability Scorecard Bonsucro, Better Sugarcane Initiative GQA, Genesis Quality Assurance</p> <p>PEFC, Program for the Endorsement of Forest Certification schemes RTRS, Roundtable for Responsible Soy Production GGLS2, Green Gold Label 2. Agriculture Source Criteria Nordic Ecolabelling of Fuels RSB, Roundtable on Sustainable Biofuels RSPO, Roundtable on Sustainable Palm Oil SBA, Sustainable Biodiesel Alliance RFS2, Renewable Fuel Standard, the United States, 2010 RTFO, Renewable Transport Fuel Obligation – UK Directive 2009/28/EC of the European Union BLCAO, Biofuels life cycle assessment ordinance Swiss Confederation BioNa Dv, Biomass Sustainability order, Germany SAN/RA, Sustainable Agriculture Network/Rain forest Alliance</p>	
	PRINCIPLE 13. Energy efficiency and use of renewable energy should be promoted in the processes that are part of the biodiesel supply chain		
	<p>CRITERION 39: Energy used in the biodiesel supply chain from renewable sources.</p> <p>CRITERION 40: Energy savings in the biodiesel supply chain with compared to the previous year.</p>	<p>INDICATOR 155. Report total annual fuel consumption from renewable fuel sources in joules or multiples, including fuel types used</p> <p>Report total annual fuel consumption from non-renewable sources in joules or multiples, including fuel types used</p>	<p>(Musango et al. 2011) (Edgard Gnansounou 2011) (Wang, Calderon, et Lu 2011) (McBride et al. 2011) (Buchholz, Luzadis, et Volk 2009) (Markevičius et al. 2010) (Kurka et Blackwood 2013) LEAF, Linking Environment and Farming ISO 14040 - Life Cycle Assessment SBA, Sustainable Biodiesel Alliance</p> <p>GBEP, Global Bioenergy Partnership SAN/RA, Sustainable Agriculture Network/Rain forest Alliance Interamerican Development Bank-Sustainability Scorecard Bonsucro, Better Sugarcane Initiative UNEP, 2009. Towards Sustainable Production RSB, Roundtable on Sustainable Biofuels RSPO, Roundtable on Sustainable Palm Oil</p>
		<p>INDICATOR 153. Amount of energy generated for a kg of biodiesel / Amount of energy consumed in the extraction stages and palm oil to biodiesel oil transformation per kilogram of biodiesel $[(\sum(\text{kJ Electricity} + \text{kJ Fuel Oil} + \text{kJ Gas} + \text{kJ Coal} + \text{kJ Steam} + \text{kJ Other})) / \text{kg biodiesel}]$</p>	

