SCORELCA

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LIFE CYCLE ASSESSMENT OF BIOMASS ENERGY : STATE OF THE ART, METHODOLOGICAL CHALLENGES AND RECOMMENDATIONS

SYNTHESIS IN ENGLISH

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POLYTECHNIQUE MONTRÉAL

SCORE LCA is an association that has been created to financially support collaborative research on LCA and related topics. It aims to promote and organize cooperation between companies, institutional and scientists in order to support the evolution of LCA methods and its practical implementation at European and international level.

- ✓ This work has been supported by ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie) www.ademe.fr

- ✓ The views and recommendations expressed in this publication are those of the authors and do not necessarily reflect, unless otherwise stated, the views of all members of SCORE LCA.

- ✓ The information and conclusions presented in this document were established on the basis of scientific and technical data and regulatory and normative framework in force at the date of the publication of documents.

Objectives of the study

The general objectives of this study are to **analyze current practices to perform bioenergy LCAs** and to **provide recommendations on the best current and future practices**.

The specific objectives are:

1. To identify current pathways regarding biomass energy (or bioenergy) production;
2. To inventory the claims of different stakeholders about the environmental performances of bioenergy, thus potentially justifying the use of bioenergy;
3. To define the theoretical concepts of LCA of bioenergy;
4. To inventory the main normative guidelines to conduct an LCA of bioenergy;
5. To perform a literature review of the recent literature on LCAs of bioenergy to identify the main methodological choices influencing results;
6. To perform a critical analysis of the main methodological issues related to LCAs of bioenergy;
7. To perform a critical review of some reference data linked to LCAs of bioenergy;
8. To test the influence of several methodological challenges through an application of a case study;
9. To provide short- and long-term recommendations on best practices when performing LCAs on bioenergy.

This document is a synthesis of the complete report which is available in French on the website of SCORELCA: https://www.scorelca.org/.

1 Identification of biomass energy production pathways

Biomass energy, or bioenergy, is energy produced from renewable biomass. The objective of this section is to identify and classify the main pathways to produce biomass energy, depending on their technical characteristics. 120 pathways have been identified, including 66 pathways for liquid biofuels (Table 1-3), 29 pathways for gaseous bioenergy (Table 1-1), 24 pathways for fuels from solid biomass (Table 1-2) and finally 1 pathway from bioelectricity. An overview of the current market of bioenergy is also available at the end of this section.

Table 1-1: Classification of the gaseous bioenergy pathways (biogas, biomethane and hydrogen)

Bioenergetic product	Biomass type	Conversion process	Potential use
Biogas	Agriculture residues	Anaerobic digestion	Heat + Electricity
	Biomass wastes	(landfill gas)	
Biomethane	Agriculture residues	Anaerobic digestion + Purification	Heat + Electricity + Road transportation / Vehicles using natural gas
	Biomass wastes	Purification	
Synthetic natural gas (SNG)	Agriculture residues	Anaerobic digestion+ Methanation	Heat + Electricity + Road transportation / Vehicles using natural gas
	Biomass wastes		
	Dedicated energy crops	Gasification + Methanation	
	Wood wastes		
	Agriculture residues		
	Algae		
Biohydrogen	Agriculture residues	Dark fermentation	Road transportation / Fuel cell vehicles
	Biomass wastes		
	Dedicated energy crops	Gasification	
	Wood wastes		
	Agriculture residues		
	Algae		
	Algae	Photobiologic production of hydrogen	

Table 1-2: Classification of the solid bioenergy pathways (fuel from solid biomass)

Bioenergetic product	Biomass type	Conversion process	Potential use
Wood logs	Raw wood	Wood fuel preparation	Heat
Wood briquettes	Raw wood	Wood fuel preparation	Heat + Electricity
	Dedicated energy crop		
	Wood residues		
	Biomass wastes		
Wood pellets	Raw wood	Wood fuel preparation	Heat + Electricity
	Dedicated energy crop		
	Wood residues		
	Biomass wastes		
Wood chips	Raw wood	Wood fuel preparation	Heat + Electricity
	Dedicated energy crop		
	Wood residues		
	Biomass wastes		

Table 1-3: Classification of the liquid bioenergy pathways (biofuels and bioliquids) (*can include organic matter from fossil origin)

Bioenergetic product	Biomass generation	Biomass type	Conversion process	Potential use
Bioethanol	G1	Conventional crops	Ethanol fermentation	Road transportation / Conventional vehicles + Road transportation / Flex-fuel vehicles
	G2	Dedicated energy crop	Enzymatic hydrolysis	
		Agriculture residues		
		Wood residues		
	G3	Algae		
	Advanced	Biomass wastes		
Biodiesel (FAME)	G1	Conventional crops	Lipid extraction + Transesterification	Road transportation/ Conventional vehicles + Sea transportation
	G1bis	Dedicated energy crops		
	G2	Agriculture residues		
	G3	Algae		
	Advanced	Biomass wastes		
HVO (Renewable diesel)	G1	Conventional crops	Lipid extraction + Hydrotreatment	Road transportation/ Conventional vehicles + Air transportation
			Lipid extraction + Co-treatment*	
	G1bis	Dedicated energy crops	Lipid extraction + Hydrotreatment	
			Lipid extraction + Co-treatment*	
	G2	Dedicated energy crops	Pyrolysis + Hydrotreatment	
		Agriculture residues	Lipid extraction + Hydrotreatment	
			Lipid extraction + Co-treatment*	
			Pyrolysis + Hydrotreatment	
		Wood residues	Pyrolysis + Hydrotreatment	
	G3	Algae	Lipid extraction + Hydrotreatment	
			Lipid extraction + Co-treatment*	
			Pyrolysis + Hydrotreatment	
	Advanced	Biomass wastes	Lipid extraction + Hydrotreatment	
			Lipid extraction + Co-treatment*	
			Pyrolysis + Hydrotreatment	
FT liquids	G2	Dedicated energy crops	Gasification + Fischer-Tropsch	Road transportation/ Conventional vehicles + Air transportation
		Agriculture residues		
		Wood residues		
	G3	Algae		
	Advanced	Biomass wastes		
Other synthetic biofuels	G2	Dedicated energy crops	Gasification + Fischer-Tropsch	
		Agriculture residues		
		Wood residues		
	G3	Algae		
	Advanced	Biomass wastes		
Raw vegetable oil	G1	Conventional crops	Lipid extraction	Road transportation / Other
	G1bis	Dedicated energy crops		
	G2	Agriculture residues		
	G3	Algae		
	Advanced	Biomass wastes		
Bio-oil	G2	Dedicated energy crops	Pyrolysis	Heat + Electricity
		Agriculture residues		
		Wood residues		
	G3	Algae		
	Advanced	Biomass wastes		

2 Critical analysis of claims related to the sustainability of bioenergy

The objective of this section is to identify and categorize claims related to the environmental performances of bioenergy and more broadly, related to the sustainability of bioenergy. The analysis considers claims both in favour and against the use of bioenergy according to numerous sources (European associations of bioenergy producers, parastatal bodies or not governmental bodies, scientific literature). The most common claims were reformulated in quotes and made clear in the report. Particular attention was carried out to avoid interpretation and judgement from the authors of this study, during the reformulation process. The claims were categorized into 10 groups: Renewable energy, Competition with food, Climate change, Carbon neutrality and negative emissions, Land use and land use change, Soil quality and carbon storage, Biodiversity, Air quality, Water quality and water use, Circular economy and energy security.

3 Critical analysis of the state of the art in bioenergy LCAs

This section aims to identify the guidelines and current practices for performing LCAs on biomass energy.

3.1 Theoretical concepts on LCAs of pathways to produce bioenergy

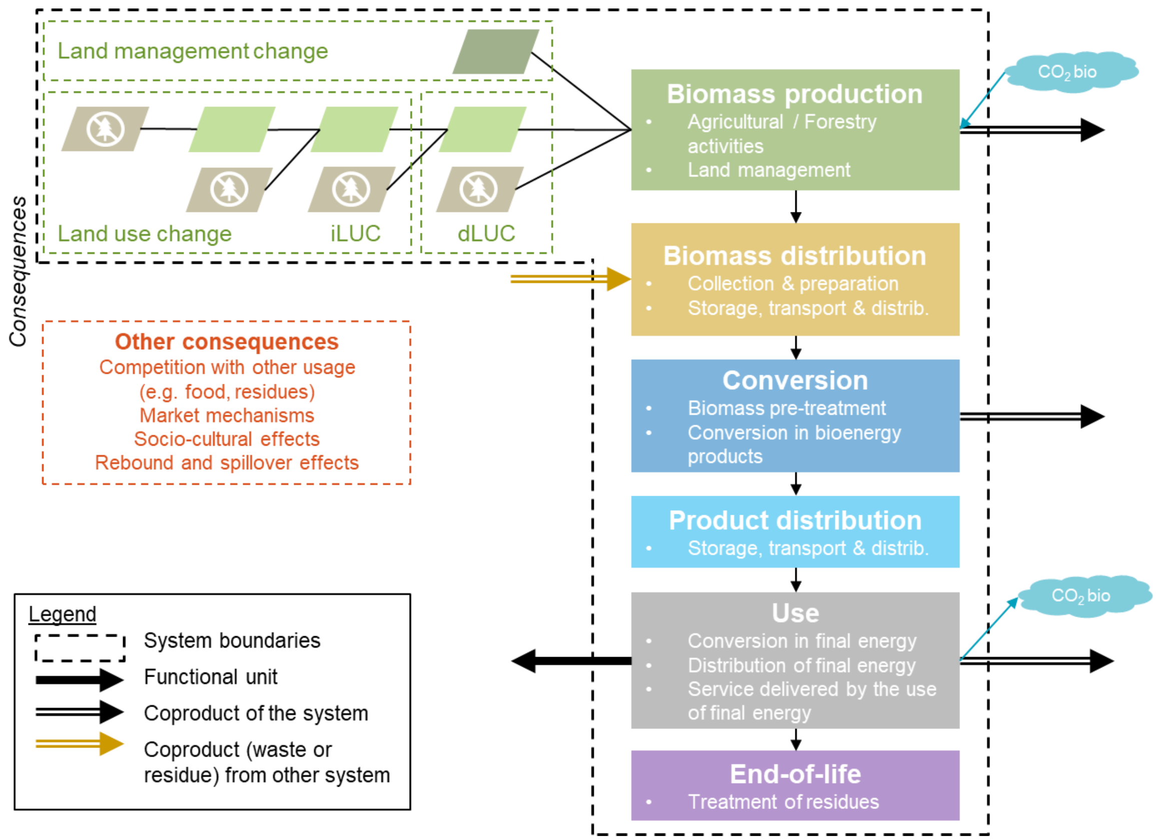

Figure 3.1 Process tree of a typical bioenergy pathway life cycle

As with any human activity, bioenergy pathways generate direct and indirect potential environmental damages on the 3 different areas of protection (AoP): Human health (HH), Ecosystem quality (EQ) and Resources and ecosystem services (RES).

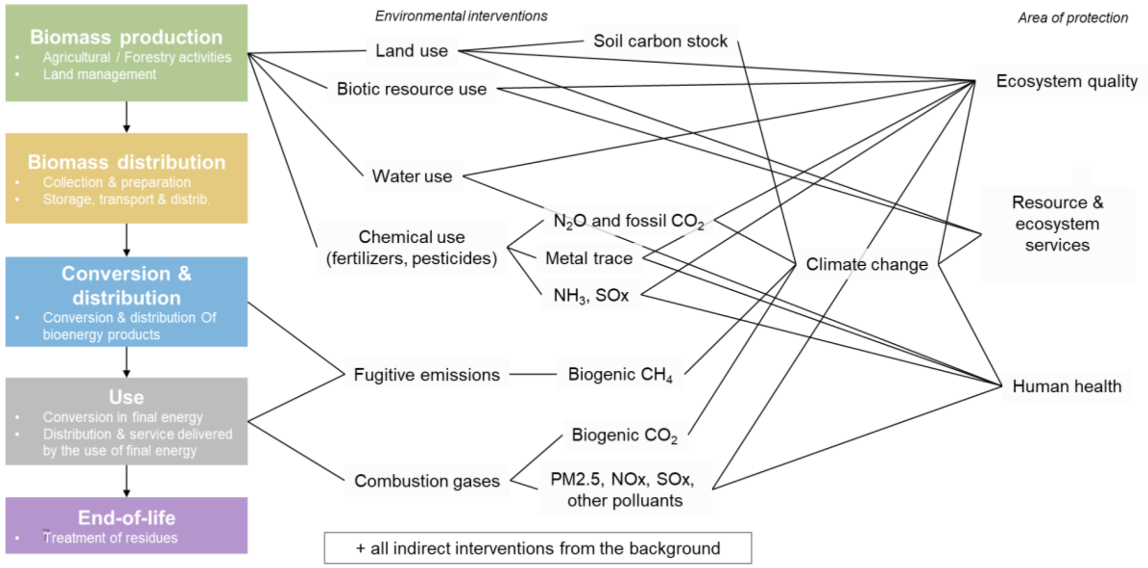

Figure 3.2 Link between the damages on AoP and the main environmental interventions directly generated by the life cycle of bioenergy pathways

3.2 Review of the guidelines for performing LCAs of bioenergy

The objective of this section is to identify the main normative guidelines to perform LCAs on bioenergy. Guidelines come from different normative texts linked to the environmental performances of biomass energy (regulation, standards and systems of certification). Only normative texts including a sustainability criterion based on LCA were further analyzed, by focusing the review on the guidelines related to the main methodological issues that arise while performing an LCA of bioenergy. The review focuses on the guidelines currently implemented within the European Union and proposes a comparison with the guidelines implemented in North America, specifically when it comes to regulations. The normative texts further analyzed in the report are:

- Regulations: RED II (European regulation for renewable energies), LCFS, RFS (two American regulations on biofuels) and CORSIA (International regulation of aviation fuels).
- Standards: GHG Protocol – Standard on products, ISO 14067:2018 – Carbon footprint for products and EN 16760 – bio-sourced products– Life cycle assessment.
- Certification systems: Roundtable of Sustainable Biomaterials (RSB)

3.3 Critical analysis of the literature on LCAs of bioenergy

The goal of this section is to identify the current practices linked to the most influential methodological choices made within published LCAs on biomass energy pathways. First, the main findings of 22 “review-type” publications on the topic were inventoried. Then, the conclusions of 27 other published LCA studies (“case study-type”), which were not covered by the “review-type” publications, were also analyzed.

The main methodological challenges revealed by this analysis of the literature are:

1. The choice between an attributional (ALCA) or consequential (CLCA) modelling approach
2. Choice of the functional unit (FU)
3. Choice of the system boundaries
4. Treatment of the issues related to multifunctionality
5. Accounting for biogenic carbon
6. Land use and land use change (LULUC)
7. Choice of the inventory data used to model bioenergy life cycles
8. Environmental life cycle impact assessment (LCIA)
9. Interpretation and reference scenario

4 Critical analysis of methodological issues related to LCAs of bioenergy and main recommendations

The following section recaps the main methodological issues related to the LCAs of bioenergy identified in the literature or identified by the authors of this report. For each issue, its nature and influence are discussed, the existing approaches to treat this issue are identified, and the best practices and current limitations are also highlighted. This analysis is the basis for the formulation of recommendations for the short and long term, for each issue. This section aims to be educational by explaining the methodological challenges and aims to bridge the gap between LCA practitioners and developments in research.

Tableau 4.1 Main short-term and long-term recommendations per methodological issue

Methodological issue	Short term recommendations	Long term recommendations
ALCA vs CLCA	• Choose a modelling approach consistent with the goal and scope (G&S) + decisional context (ILCD) • Help for policymakers = CLCA • Include higher order of consequences in CLCA • Use the ILCD handbook to identify processes to be included in CLCA	• Better modelling of bioenergy use phase and interaction with users (rebound effects) • Better access and transparency of economic models used for use on CLCA
Functional unit	• Choose UF consistently with G&S and perceptive of the targeted audience • A precise formulation of FU (qualitative and quantitative) to reflect the representativity context of the study • FU should ideally represent the common functionality of compared systems • Redefining FU is a way to avoid allocation • Perform sensitivity analysis on FU choice to capture different potential issues	• Propose a clear framework to define FU for bioenergy pathways
System boundaries	• Should be consistent with G&S and chosen FU • Initial boundaries = cradle to grave → iterative process • Exclusions should be justified: qualitatively and quantitatively identical processes in the foreground, cut-off criteria based on impact contribution for background • Always include infrastructures for final conversion (ex. Furnace, car) when comparing systems that are not using the same • Include production infrastructure, if possible, in particular for biogas pathways	

Methodological issue	Short term recommendations	Long term recommendations
Multifunctionality	• Identify all cofunctions + nature of coproducts (by-products? Waste?) • Choose an approach to treat multifunctionality consistently with G&S + justify the choice (especially why ISO hierarchy has not been applied) • Redefine system boundaries if necessary (system expansion) • Perform sensitivity analysis on approaches to treat multifunctionality • Justify the choice of substitution pathways, ideally considering the substitution potential	• Facilitate access to price data for economic allocation
Biogenic carbon	• Not applying carbon neutrality should be preferred → manually adjust biogenic carbon balance if necessary • Apply carbon neutrality only for short life cycles → not forest-based bioenergy • Adjust GWP/GTP for biogenic flows when applying carbon neutrality • Carbon neutrality can be justified when biomass EoL or biomass production is excluded from system boundaries (ex. WTT or waste valorization) • Dynamic LCIA modelling is needed for forest-based bioenergy (dynamic LCA or GWPbio) • The choice of temporal allocation of carbon sequestration to harvested activities should be consistent with the G&S + type of forest management • Altitude effects on GWP/GTP should be considered for the aviation sector	• Provide LCI DB with high-quality data on bioenergy
LULUC	• Always include the impacts of land occupation and transformation on climate change. • Include other impacts of LULUC when characterization factors (CF) are available (soil quality, biodiversity) • Choose the most relevant tool to identify LUC depending on the study resources • Include land management effect when assessing LUC • Include indirect land use change (iLUC) when possible. Use the default values provided by regulation at least. • Prefer a degressive linear amortization of impact from LUC (ILCD recomm.) • Use Müller-Wenk & Brandão 2010 for land occupation. • Use Tier 1 IPCC 2006 or Müller-Wenk & Brandão 2010 for land transformation. • The contribution of LULUC impacts to CC should be reported separately	• Facilitate iLUC identification for LCA practitioners • Continue to develop LCIA indicators related to LUUC, especially to better account for impacts and benefits on ecosystem services.

Methodological issue	Short term recommendations	Long term recommendations
Inventory data	• Use primary data for foreground modelling if available • Pay attention to the representativeness of secondary data. Adapt them if needed. • Regionalize the inventory for biomass production steps • Mention data limitations	• Provide LCI DB with high-quality data on bioenergy
LCIA	• Prioritize impact category to be included based on their contribution to damage • Prefer to use a midpoint-damage LCIA methodology if consistent with G&S • Adjust GWP/GTP for biogenic flows when applying carbon neutrality • Altitude effects on GWP/GTP should be considered for the aviation sector • Account for the dynamic of GHG emissions for a long life cycle (forestry) • Always include a primary energy consumption indicator to assess the energy efficiency of the bioenergy pathway.	• Develop LCIA method for use of non-natural biotic resources • Develop an operational framework + LCIA indicators to account for impacts on ecosystem services
Interpretation	• Account for the substitutability potential when comparing pathways. At least qualitatively comment on how relevant their comparison is. • Always perform sensitivity analysis	• Provide practical recommendations on comparability between bioenergy pathways or with fossil reference considering their substitution potential. • Facilitate access for LCA practitioners to sensitivity analysis based on a high number of scenario

5 Critical analysis of reference data related to LCA's of biomass energy

The approaches used for each previously identified methodological issue are described and the resulting limitations and shown. Analyzed data sources are Boulamanti et al (2013), Studies JEC WTT WTW v5, GREET models and Ecoinvent v3.8.

6 Case study

A case study was performed to demonstrate practically the application of some of the methodological choices and to demonstrate the influence of these choices on the results. The main function studied in this case study was the production of biomethane from biogas in the current French context. The 6 pathways that were chosen for this application were all derived from the production of methane from the purification of biogas coming from anaerobic digestion. The methodological issues that were tested as sensitivity analysis were: the choice of the functional unit, the choice of system boundaries, the treatment of multifunctionality, the integration of biogenic carbon, and the choice of the impact assessment methodology.