Project acronym: # EuroBioRef

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SP1 – GENERAL STRATEGY FRAMEWORK FOR A SUSTAINABLE INTEGRATED BIOREFINERY

WP1.2 – STATE-OF-THE-ART OF THE INVOLVED SUB-PROCESSES AND OF THE WHOLE BIOMASS VALUE CHAIN

Deliverable report

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Content

Executive summary

Description of the deliverable objective and content

Deliverable D1.2.3-2 is linked to Task 1.2.3 named “Performing LCA for biorefineries and socio-economic modeling review”.

The scope of this task is to establish the state of the art for assessing environmental burdens of a biorefinery. This state of the art serves as a basis for the preliminary assessment of the initial biorefinery scenarios and development of an adapted methodology according to objectives of WP9.1.

This document updates the first version of D1.2.3-1 “Literature review establishing the state of the art of LCA applied to biorefineries, to be published in a peer reviewed scientific journal.” delivered on M12. This deliverable will be updated in M36 and M48 according to task T1.2.3.

Publishable information

According to the DoW, the last version of this deliverable updated at M48, will be published in a peer review scientific journal.

Conclusion

The present document is concerned with a literature review establishing the state-of-the-art of LCA applied to biorefineries. It provides an updated version of the literature review delivered in M12 and shall be updated and consolidated again in M36 and M48 according to Task T1.2.3.
The present review focuses mainly on three topics concerning environmental issues, including: raw material inventories, biorefinery processes and LCA methodological issues.
Although there does not seem to be a consensus on best practises, some methodological choices stand out as key elements concerning the application of LCA to the context of biorefineries. In particular, the choice of the allocation method may significantly affect the environmental performance of biorefineries. Land-use change (direct and whenever possible indirect) shall be taken into account in order to reflect the true impacts (positive or negative) of biorefineries on the environment. Finally, consequential versus attributional LCA is a much debated topic among LCA practitioners, although none of the two seems to really stand out as the best-practise approach (being strongly related to the goal and scope of the LCA study).
The various aspects above shall be further developed in the next phase of the project.

ANNEX I – Technical content

The literature review focuses on three topics concerning environmental issues: raw material inventories, biorefinery processes and LCA methodological issues.

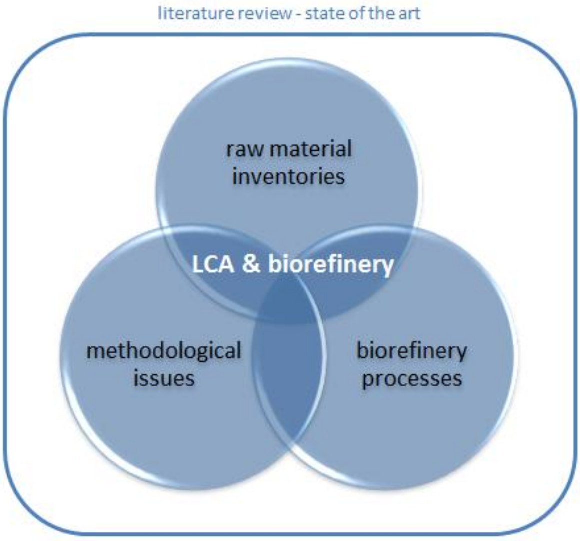

Figure 1 Main topics concerned by literature review.

Definitions

For the purposes of this document, the following terms and definitions apply issued from International Organization for Standardization (ISO) guidelines (ISO 14040: 2006).

life cycle
consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal

life cycle assessment (LCA)
compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle

life cycle inventory analysis (LCI)
phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle

life cycle impact assessment (LCIA)
phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product

Literature review

Biofuels and bio-products are produced in two distinct stages: feedstock production (or collection) and processing.
This literature review first aims to gather life cycle inventories (LCI) of raw material concerning feedstock production. Secondly, the aim of this review is focused on processing, sometimes called conversion or biorefining. The scientific literature about the application of LCA methodology to biorefinery systems is nowadays limited. However, biorefinery processes represent the core topic of EuroBioRef project from the LCA point of view and some interesting references are available.
Third, the last main objective of this literature review is about methodological issues. Applying LCA in biorefinery context raises methodological issues as allocation choices, land use change and indirect land use change, N_2O emissions from fertilizers and biogenic carbon cycle accounting.

Concerning raw material inventories, literature offers many papers about different sources of biomass. Raw material inventories for first generation biofuels are given by different studies as for examples (ADEME 2010) or (Jungbluth et al. 2007). Many other papers are signalled in "Appendix II: Literature review establishing the state of the art of LCA applied to biorefineries".
More pertinent raw material inventories for this project are published for examples by (Bai et al. 2010) and (Cherubini et al. 2010) concerning switchgrass; by (Cherubini et al. 2009) concerning corn stover and wheat straw; by (Jungbluth et al. 2007a) and (Jungbluth et al. 2008) concerning short rotation wood (willow-salix or poplar), miscanthus and wheat straw; by (Kim et al. 2009) concerning corn stover; by (Bonjean 1991) and (Mittal et al. 1991) concerning castor crop; by (Uihlein et al. 2009) concerning straw; by (Whitaker et al. 2009) concerning jatropha. The discussion is on-going with SP2 members to make sure that the data included in these studies can be used directly and is representative of agronomic practices done in EuroBioRef. Useful data about raw material inventories will be given in the deliverable D1.2.1 named "Updated bibliographic study, statistics on biomass feedstock availability and potential new biomass resources".

Concerning the state of the art of LCA applied to biorefinery, (Cherubini et al. 2009) and (Cherubini et al. 2010) give inventory data for electricity, heat demand and auxiliary materials in biorefinery concept producing bioethanol, bioenergy and chemicals from switchgrass.
(Uihlein et al. 2009) provide data about lignocellulose feedstock (straw) biorefinery system. Inputs information is available as electricity, heat, water, hydrochloric acid and hydrogen needs. Different alternatives are analyzed from basic biorefinery concept to optimized ones with different rates of acid and heat recoveries.
Concerning the functional unit definition, LCA studies are often performed using a functional unit that refers to the output products of a process. In the context of the biorefineries, the output co-products are not clearly defined and can vary from one biorefinery to another. Consequently, in general the inventories of biorefinery processes are calculated for a reference flow of an amount of biomass treated in the biorefinery. The literature references (Cherubini et al. 2009), (Cherubini et al. 2010) and (Uihlein et al. 2009) use the same approach.
Concerning the biorefinery processes, (Laser et al. 2009) presents a qualitative description of fourteen technology biomass refining scenarios, involving both biological and thermochemical processing.

The last main topic treated in this literature review is about methodological issues, which are fundamental in LCA of biorefinery.

Some basic concepts as gross calorific value or carbon content are treated by (Sarlos et al. 2003).

Allocation choices are very important in biorefinery context and they are treated by each paper about biofuels and bioproducts. For example, energy content allocation is used by (Bai et al. 2010), (Cherubini et al. 2009) and (Cherubini et al. 2010) (i.e. repartition among different co-products is expressed in % of feedstock energy value) and economic allocation is used by (Jungbluth et al. 2007) and (Jungbluth et al. 2008). (Renouf et al. 2010) examines the preferred approach for assigning impacts to the multiple products considering allocation choices. (Cherbini et al. 2011a) assesses how different allocation methods affect the environmental performances of a lignocellulosic biorefinery. The following allocation procedures are applied: system expansion (also named substitution method), partitioning method according to different features of co-products (mass, energy, exergy and economic value), and hybrid approach (given by a combination of the previous ones).

Another fundamental methodological topic is land use change. For example, (Kim et al. 2009) treats the effect of changes in soil organic carbon level and (Cherubini et al. 2010) treats land use change effects considering the effects of crop residue removal too. (Searchinger et al. 2008) focuses on the value of biofuels from waste products because they can avoid land use change and its emissions. In their largely discussed work, (Fargione et al. 2008) and (Searchinger et al. 2008) showed the importance of including land-use change emissions in the GHG balance of biofuels. Indirect land use change (ILUC) is treated by (Fritsche et al. 2010) in order to include greenhouse gases emissions from ILUC in regulatory policies for biofuels.

An important variable in LCA studies of biomass systems is the contribution to greenhouse gases emissions of N_2O, which evolves from nitrogen fertilizer application. (IPCC 2006), (ADEME 2010) and (Gärtner et al. 2003) give default emissions factors to estimate these emissions (direct and indirect) from land. (Reijnders et al. 2011) discusses N_2O emissions models treating some critical factors as cropping system, climate, reference land use system, allocation strategy and time horizon.
(Delucchi et al. 2003) gives default emissions factors to estimate CH_4 emissions from land due to reduction of oxidation of methane in aerobic soil related both to the use of nitrogen fertilizer and cultivation type.

Concerning biogenic carbon, by default, it is not considered in the LCA related to global warming (i.e., both intake by plants and release during degradation/consumption). For example (Kim et al. 2006) does not take into account carbon uptake from atmosphere because it will be released in the downstream portions of the system.
For specific cases where release of biogenic carbon can be significantly longer after its capture (e.g., biopolymers stored in landfill, wood used for construction, etc.), the benefit from storing carbon during a certain time should be considered in the analysis. (Brandão et al. 2010) and (Levasseur et al. 2012) summarize the discussions about the method to account for the benefits, if any, of temporary carbon storage for use in the environmental assessment of products.

The discussion about attributional and consequential modelling in biofuel context is still a debated topic as confirmed by literature as (Brander et al. 2009) and (Dandres et al. 2011). (Schmidt 2008) presents a framework for defining system boundaries in consequential agricultural LCA.

Table 1 summarizes the most pertinent contributions in EuroBioRef context from literature review establishing the state of the art of LCA applied to biorefineries.
“Appendix II: Literature review establishing the state of the art of LCA applied to biorefineries” gives the details of literature review with exact references and description of main information.

Table 1 Most pertinent contributions from literature review establishing the state of the art of LCA applied to biorefineries. The **bold** references are added to the version delivered on M12.

Reference		Raw material inventories	Biorefinery processes	Methodological issues
ADEME	2010	+	+	++
Bai et al.	2010	+++	++	+++
Bonjean	**1991**	**++**	**-**	**-**
Brander et al.	**2009**	**-**	**-**	**+++**
Brandão et al.	**2010**	**-**	**-**	**+++**
Cherubini et al.	**2011**	**-**	**-**	**++**
Cherubini et al.	**2011a**	**-**	**-**	**++**
Cherubini et al.	2010	+++	+++	++
Cherubini et al.	2009	++	+++	+++
Dandres et al.	**2011**	**-**	**-**	**+++**
Delucchi et al.	2003	-	-	+++
Fargione et al.	**2008**	**-**	**-**	**+++**
Fritsche et al.	**2010**	**-**	**-**	**+++**
Gärtner et al.	2003	+	++	++
IPCC	2006	-	-	+++
Jungbluth et al.	2008	+++	+	++
Jungbluth et al.	2007	+	++	++
Jungbluth et al.	2007a	+++	+	++
Kim et al.	2005	+	++	+++
Kim et al.	2006	-	+	++
Kim et al.	2009	++	-	++
Laser et al.	**2009**	**-**	**++**	**-**
Levasseur et al.	**2012**	**-**	**-**	**+++**
Mittal et al.	1991	+++	-	-
Reijnders et al.	**2011**	**-**	**-**	**+++**
Renouf et al.	2010	+	++	+++
Sarlos et al.	2003	-	-	+++
Schmidt	**2008**	**-**	**-**	**++**
Searchinger et al.	**2008**	**-**	**-**	**++**
Uihlein et al.	2009	++	+++	-
Whitaker et al.	2009	+++	++	+++

This literature review about LCA applied to biorefinery will be updated in the next steps of EuroBioRef project. Partners of EuroBioRef will be contacted to provide information if possible to this literature review and the WP9.1 will deal with the applicability of those literature data to feed the life cycle assessment modelling, in collaboration with various partners of EuroBioRef (as SP2 for crops and transportation). The objective of WP 9.1 is to complete those literature data with primary data collected by all partners of EuroBioRef.

Key findings:

- A draft version of the literature review about LCA applied to biorefinery concept has been realized focusing on 3 main topics: raw material inventories, biorefinery processes and methodological issues.
- According to task T1.2.3, literature review will be updated in M36 and M48.

Appendix II: Literature review establishing the state of the art of LCA applied to biorefineries

Author	Date	Title	Journal / Source	Scope	Raw material inventories	Biorefinery processes	Methodological issues
ADEME	2010	ACV appliquées aux biocarburants de première génération consommés en France	www.ademe.fr	Establish the environmental impacts of various first generation biofuels. Compare the ethanol and ester biofuels with the diesel and petrol.	Wheat, maize, sugar beet, sugar cane, rapeseed, rapeseed pure oil, soybean, palm, used oils, animal fats, ETBE, conventional diesel and petrol	All inputs considered: energy consumed and chemicals. Direct emissions related considered.	Allocation for the GHG emissions and non-renewable primary energy: If the co-products are: - spread or used to produce energy: substitution - used as animal feed or in industry: energetic ratio between the co-products (MJ/kg DM) The same allocation procedure can be used as a first evaluation for the other indicators. N_2O emission factor accounts for direct and indirect emissions from a variety of organic and synthetic nitrogen fertilizer.
Bai Y., Luo L., Van der Voet E.	2010	LCA of switchgrass-derived ethanol as transport fuel	Int J LCA (2010) 15:468-477	It assess the environmental impact of using ethanol from switchgrass as transport fuel and compares the results with the ones of gasoline.	Switchgrass agriculture process.	Conversion of switchgrass to ethanol in four steps: feedstock pretreatment, enzyme hydrolysis, fermentation, and production recovery.	An allocation (between bioethanol and electricity) based on energy content was applied as a baseline in line with EU Rirective 2009 (2009/28 EC 2009), and market price-based allocation was applied for sensitivity analysis.
Bonjean A	1991	Castor cultivation for chemical applications	Collection Agripoche, Galileo/Onidol	This book focuses on castor information. It presents pararcteristics and origins of the species, history of origins and breeding, cultivation and european and global outlook.	Data about castor cultivation.	-	-
Brandão M, Levasseur A	2010	Assessing Temporary Carbon Storage in Life Cycle Assessment and Carbon Footprinting Outcomes of an expert workshop	JRC Scientific and Technical Reports. EUR 24829 EN - 2011	This document is a summary of the presentations and discussions held during the workshop organized by the JRC about the assessment of temporary carbon storage in LCA and carbon footprinting.	-	-	This document presents the discussions about the method to account for the benefits, if any, of temporary carbon storage for use in the environmental assessment of products.

Author	Date	Title	Journal / Source	Scope	Raw material inventories	Biorefinery processes	Methodological issues
Brander M, Tipper R, Hutchison C, Davis G (Ecometrica), Arkhurst M (BP)	2009	Consequential and attributional approaches to LCA: a guide to policy makers with specific reference to greenhouse gas LCA of biofuels.	Technical Paper TP-090403-A. Ecometrica press. April 2009.	This paper sets out the key differences between consequential and attributional LCA.	-	-	The paper assesses which method is applied in the carbon reporting guidance for the UK's Renewable Transport Fuel Obligation (RTFO) and EU's Renewable Energy Directive (RED), or whether a mixture of the methods is used. RTFO guidance adopts a partial consequential LCA approach but that there are inconsistencies in the treatment of co-products and attributional LCA derived fossil fuel comparators are compared to partial consequential LCA biofuel values. The LCA method used in the RED is largely consistent with attributional LCA, but this may not be the most suitable method for determining total greenhouse gas impacts, which is one of the main purposes of carbon reporting in relation to biofuels policy.
Cherubini F, Strømmana A H	2011	Life cycle assessment of bioenergy systems: State of the art and future challenges	Bioresource Technology 102 (2011) 437–451	This paper performs a review of a large portion of the existing scientific literature that explicitly used life cycle assessment (LCA) methodology, or a life-cycle approach, to estimate the environmental impacts of biomass energy uses.	-	-	This work points out and discuss the key issues and methodological assumptions responsible for wide ranges and uncertainties in bioenergy LCA. The article presents a discussion about for example: the definition of the functional unit, the reference system (attributional or consequential LCA), change in carbon pools and land-use changes and allocation issues.
Cherubini F, Strømmana A H, Ulgiati S	2011a	Influence of allocation methods on the environmental performance of biorefinery products - A case study	Resources, Conservation and Recycling 55 (2011) 1070– 1077	The aim of this paper is to assesses how different allocation methods affect the environmental performances of a lignocellulosic biorefinery. The following allocation procedures are applied: system expansion (also named substitution method), partitioning method according to different features of co-products (mass, energy, exergy and economic value), and hybrid approach (given by a combination of the previous ones).	-	-	Allocation procedures : system expansion, partitioning method according to different features of co-products (mass, energy, exergy and economic value), and hybrid approach (given by a combination of the previous ones).

Author	Date	Title	Journal / Source	Scope	Raw material inventories	Biorefinery processes	Methodological issues
Cherubini F., Jungmeier G.	2010	LCA of biorefinery concept producing bioethanol, bioenergy, and chemicals from switchgrass	Int J LCA (2010) 15:53-66	Comparison with a fossil reference system producing the same products/services from fossil sources	Inventory for cultivation, production and delivery of switchgrass pellets.	Inventory for electricity and heat demand; these energy needs are completely met by heat and power internally produced by combustion of lignin and residues. Auxiliary material used and emissions from combustion are estimated. Production of bioethanol, electricity, heat and phenols; repartition is expressed in MJ: % of feedstock energy value.	Land use change effects and soil N_2O emissions.
Cherubini F., Ulgiati S.	2009	Crop residues as raw materials for biorefinery systems - A LCA case study	Applied Energy 87 (2010) 47-57	It focuses on a biorefinery concept which produces bioethanol, bioenergy and biochemicals from two types of agricultural residues: corn stover and wheat straw. The systems are compared with the respective fossil reference systems.	Two types of agricultural residues: corn stover and wheat straw. All the agricultural inputs required to grow the crops are not accounted for because they are assumend to be completely allocated to the grains.	Inventory for electricity and heat demand; these energy needs are completely met by heat and power internally produced by combustion of lignin and residues. Auxiliary material used and emissions from combustion are estimated. Production of bioethanol, electricity, heat and phenols; repartition is expressed in MJ: % of feedstock energy value.	Land use change aspects, i.e. the effects of crop residue removal (like decrease in grain yields, change in soil N_2O emissions and decrease of soil organic carbon). Allocation: all the agricultural inputs required to grow the crops are not accounted for because they are assumend to be completely allocated to the grains.
Cherubini F	2010	The biorefinery concept: Using biomass instead of oil for producing energy and chemicals	Energy Conversion and Management 51 (2010) 1412–1421	This paper provides a description of the emerging biorefinery concept, in comparison with the current oil refinery. The focus is on the state of the art in biofuel and biochemical production, as well as discussion of the most important biomass feedstocks, conversion technologies and final products.	Composition of some lignocellulosic feedstocks are given: softwood, swithgrass, corn stover and wheat straw.	A qualitative description is given for thermochemical, biochemical, mechanical and chemical processes.	-

Author	Date	Title	Journal / Source	Scope	Raw material inventories	Biorefinery processes	Methodological issues
Dandres T, Gaudreaultb C, Tirado-Secoa P, Samson R	2011	Assessing non-marginal variations with consequential LCA: Application to European energy sector	Renewable and Sustainable Energy Reviews 15 (2011) 3121– 3132	The objective of this paper is to illustrate a new approach based on the use of sequential application of a Computable General Equilibrium Model (CGEM) and a consequential LCA to assess the environmental impacts of different energy policies. More specifically, the substitution of fossil fuels by renewable energies in Europe is addressed with a focus on EU electricity and heat generation between 2005 and 2010.	-	-	The consequential approach presented in this paper is adapted for large systems (where non-marginal perturbations involve significant volumes of goods that may affect in a non-linera way the price, the production and the consumption of commodities). It benefits both to Global Trade Analysis Project (GTAP) model and LCA method. Using this approach allows GTAP model to assess emissions and extractions according to life cycle of products produced by each economic sector instead of using economic sector emissions factor.Regarding LCA method, this new consequential approach allows studying significant changes affecting large systems with a global modeling of economy in a time dependent environment (economic growth is taken into account).
Davis S C, Anderson-Teixeira K J, DeLucia E H	2009	LCA and the ecology of biofuels	Trends in Plant Science, Vol 14, N° 3	Introduce the plant science community to LCA and review LCA on ethanols.	Corn, switchgrass, miscanthus, mixed temperate grasses.	-	-
Delucchi M A	2006	LCA of biofuels (draft manuscript)	Institute of Transportation Studies, University of California, Davis	Analysis of GHG emissions from biofuels using the Lifecycle emissions Model (LEM). Review of recent LCAs on biofuels. Establish a comprehensive conceptual framework for doing LCA on biofuels.	Corn, switchgrass, wood, soybean.	Corn, switchgrass & wood ethanol, soybean biodiesel, wood methanol, wood synthetic natural gas and switchgrass to hydrogen	-
Delucchi M. A., Lipman T.	2003	A Lifecycle Emissions Model (…) - Appendix C: emissions related to cultivation and fertilizer use	www.its.ucdavis.edu	The analysis attempts to account for many of the affects of cultivation and fertilizer use on climate. The method is similar to that recommended by the IPCC. A special attention is paid to the addition and fate of nitrogen (N) fertilizer.	-	-	Default emissions factors are given to estimate CH_4 emissions from land due to reduction of oxidation of methane in aerobic soil related both to the use of nitrogen fertilizer and cultivation type.
Dias de Oliveira M E, Vaughan B E, Rykiel Jr. E J.	2005	Ethanol as fuel: energy, carbon dioxide balances, and ecological footprint	BioScience vol 55, no 7	-	Sugarcane and corn	-	-

Author	Date	Title	Journal / Source	Scope	Raw material inventories	Biorefinery processes	Methodological issues
Farrell A E, Plevin R J, Turner B T, Jones A D, O'Hare M, Kammen D M.	2006	Ethanol can contribute to energy and environmental goals.	Science, vol 311.	6 studies reviewed. A model has been developed to enable better comparison between studies that have not the same methods and parameters.	Corn	-	A model has been developed to enable better comparison between studies that have not the same methods and parameters.
Fritsche U R, Hennenberg K, Hünecke K	2010	The "iLUC Factor" as a Means to Hedge Risks of GHG Emissions from Indirect Land Use Change - Working Paper -. Sustainability Standards for internationally traded Biomass	Öko-Institut, Darmstadt Office	The German Federal Environment Agency (UBA), on behalf of the Federal Ministry for Environment (BMU), funded research on sustainable global biomass trade. A key element in that research is to consider and elaborate on opportunities for sustainable biomass feedstock provision which have no negative or even positive environmental, biodiversity, climate, and social trade-offs.	-	-	"With regard to the GHG emission balance of bioenergy, the possible effects of direct and especially ILUC associated with cultivating biomass feedstocks are vigorously discussed. This paper introduces a deterministic approach developed by Oeko-Institut within the Bio-global project to include GHG emissions from ILUC in regulatory policies for biofuels, and giving an outlook to the range of possible future iLUC
Gärtner S. O., Reinhardt G. A.	2003	LCA of biodiesel: updated and new aspects	ifeu - Institute for Energy and Environmental Research Heidelberg GmbH	Analyze the effects of the increase in rapeseed production that has led to a rise in the availability of co-prudcts (for example rapeseed honey) and innovative new uses for these co-products. Starting with the overall comparison between RME and conventional diesel fuel, the investigation examined four key aspects: (1) preceding crop effet, (2) N_2O emissions, (3) honey production (and co-products) and (4) biogas generation from rapeseed meal.	Rapesedd cultivation.	At oil mill, rapeseed oil is extracted. The rapeseed meal accumulating as a co-product in this process is used as animal feed, substituting soy meal imported from North America. Rapeseed oil is the transformed into RME by means of a transesterification process. The resulting co-product glycerine is conditioned and used as a substitute for glycerine generated chemically.	Focus on the release of N_2O from soils caused by microbial activity.
Gnansounou E, Dauriat A, Villegas J, Panichelli L.	2009	Life cycle assessment of biofuels: Energy and greenhouse gas balances.	Bioresource technology 100, 4919-4930	Assess the sensitivity of wheat ethanol results to various parameters depending on calculation methodology and determine the most influencing parameters.	Wheat	-	Assess the sensitivity of results to various parameters depending on calculation methodology and determine the most influencing parameters.
IPCC	2006	Guidelines for national greenhouse gas inventories. Volume 4: Agriculture, forestry and other land use	www.ipcc.ch	This document provides guidance for preparing annual greenhouse gas inventories in the Agriculture, Forestry and Other Land Use (AFOLU) sector.	-	-	Default emissions factors are given to estimate N_2O emissions from land.

Author	Date	Title	Journal / Source	Scope	Raw material inventories	Biorefinery processes	Methodological issues
Jungbluth N., Büsser S., Frischknecht R., Tuchschmid M.	2008	LCA of biomass-to-liquid fuels	Schweizerische Eidgenossenschaft (BFE, BAFU, BLW)	This study elaborates a LCA of using of BTL-fuels. This type of fuel is produced in synthesis process from e.g. wood, straw or other biomass. The LCI data of the fuel provision with different types of conversion concepts are based on the detailed LCA compiled and published within a European research project.	Three types of biomass are studied: short rotation wood (willow-salix or poplar), miscanthus and wheat straw. The data were collected by regional partners from the RENEW project.	Data for the conversion processes were provided by different plant developers in the RENEW project. Where so far no reliable first-hand information is available assumptions are based on literature data.	The allocation between wheat straw and wheat grains is made with today's market prices. Biogenic emissions of NMVOC during growing of biomass are excluded from the inventory (in contrast to the original data) in order to be consistent with ecoinvent data on other types of biofuels, which also do not include these emissions.
Jungbluth N., Chudacoff M., Dauriat A., Dinkel F., Doka G., Faist Emmenegger M., Gnansounou E., Kljun N., Schleiss K., Spielmann M., Stettler C., Sutter J.	2007	Life Cycle Inventories of Bioenergy	ecoinvent report No. 17, Swiss Centre for Life Cycle Inventories	Within the first part of this project, the production and use of ethanol, biogas, BTL fuels and plant oils have been investigated. Therefore agricultural products that are needed for these fuels (grass, straw, rape seeds) are included in the analysis. The use of biofuels in different means of transportation is investigated as well. In the second part of the project a specific focus has been laid on biofuels imported to Switzerland (LCI data for biomass production and biofuel conversion in different countries).	Swiss agricultural products: grass, rape seed organic. Foreign agricultural production: corns (US), oil palm (MY), rape seed conventional (DE), rye conventional (RER), soybean (BR and US), sugar cane (BR), sweet sorghum (CN).	Biomass conversion to fuels: biogas (biowaste, sewage sludge, liquid manure, agricultural co-digestion, grass, whey), synthetic-fuels (methane and methanol from wood), ethanol 95% and 99.7%, oil-based biofuels, gaseous fuels at service station.	Allocation: market price is used as an allocation criterion if no better information is available. The energy content of the products has normally not been used to derive allocation factors. Energy resources: the demand for biogenic energy resources is considered for all agricultural and forestry products with an input of "Energy, gross calorific value, in biomass" at the frist stage of production. Biogenic carbon balance: for agricultural products the allocation fators have been calculated according to the carbon content of the allocated co-products.
Jungbluth N., Frischknecht R., Emmenegger M., Steiner R., Tuchschmid M.	2007a	Life Cycle Assessment of BTL-fuel production: Inventory Analysis	FP6 - Renew: Renewable fuels for advanced powertrains.	It is to compare different production routes of BTL fuels (Fischer-Tropsch-diesel and dimethylether) from an environmental point of view. The LCI includes all process stages from well-to-tank for BTL-fuels.	Three types of biomass are studied: short rotation wood (willow-salix or poplar), miscanthus and wheat straw. The data were collected by regional partners from the RENEW project.	Data for the conversion processes were provided by different plant developers in the RENEW project. Where so far no reliable first-hand information is available assumptions are based on literature data.	The impacts are allocated based on different principles that reflect best the causalities of material and energy flows. The modelling does not consider changes introduced by the extension of the market share of these production processes or increased production of biofuels.
Kammen D M, Farrell A E, Plevin R J, Jones A D, Nemet G E, Delucchi M A.	2008	Energy and greenhouse impacts of biofuels: A framework for analysis	UC Berkeley Transportation sustainability research center, Institute of transportation studies.	Review of existing LCA studies on biofuels, establishment of improved framework for the evaluation of biofuels.	-	-	-

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Kemppainen A J, Shonnard D R.	2005	Comparative LCA for biomass-to-ethanol production from different regional feedstocks.	Biotechnology progress 21, 1075-1084	Assess the environmental impacts of ethanol produced via fermentation-based processes with lignocellulosic feedstocks: virgin timber resources and recycled newsprint	Lignocellulosic feedstocks: virgin timber resources or recycled newsprint	-	-
Kim S., Dale B. E.	2005	LCA of various cropping systems utilized for producing biofuels: bioethanol and biodiesel	Biomass and Bioenergy, 29, 426-439	Compare the environmental impacts of various cropping systems.	Corn grain, corn stover and soybeans	Wet milling, corn stover process, soybean milling and biodiesel process. Multi-output cropping system: ethanol, corn oil/gluten meal/gluten feed, ethanol, electricity, soybean meal, biodiesl, (soapstock), glycerine.	Corn stover removal could lower the accumulation rate of soil organic carbon but could also decrease N_2O emissions from the soil and reduce inorganic nitrogen losses due to leaching.
Kim S., Dale B. E.	2006	Ethanol Fuels: E10 or E85 - Life Cycle Perspectives	Int J LCA 11 (2) 117 - 121 (2006)	The environmental performance of two ethanol fuel applications is compared : E10 fuel (a mixture of 10% ethanol and 90% gasoline by volume) and E85 fuel (a mixture of 85% ethanol and 15% gasoline by volume).	References are given for corn cultivation.	Wet milling process.	Carbon contents in biobased products are not taken into account in greenhouse gases because carbon in biobased products would be released to the atmosphere in the downstream portions of the system.
Kim S., Dale B. E., Jenkins R.	2009	LCA of corn grain and corn stover in the United States	Int J LCA (2009) 14:160-174	Estimate the environmental performance for continous corn cultivation of corn grain and corn stover grown under the current tillage practices for various corn-growing locations in US Corn Belt.	Two cropping systems are under investigation: corn produced for grain only without collecting corn stover and corn produced for grain and stover harvest.	-	The system expansion approach is used in order to estimate the environmental burdens of the corn stover alone. The effects include changes in soil organic carbon level, nitrogen-related emissions, phosphorus loss, additional nutrient requirements in the subsequent growing season, and fuel consumption in harvesting corn stover.
Lardon L, Helias A, Sialve B. Steyer J P, Bernard O	2009	LCA of biodiesel production from microalgae	Environ. Sci. Technol.	Determine if biodiesel from microalgae is environmentally interesting in comparison with conventional diesel.	Two different microalgae culture conditions have been tested.	Two different extraction options, dry or wet extraction, have been tested. This study also emphasizes the potential of anaerobic digestion of oil cakes as a way to reduce external energy demand and to recycle a part of the mineral fertilizers.	

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Laser M, Larson E, Dale B, Wang M, Greene N, Lynd L R	2009	Comparative analysis of efficiency, environmental impact, and process economics for mature biomass refining scenarios	Biofuels, Bioprod. Bioref. 3:247–270 (2009)	Fourteen mature technology biomass refining scenarios – involving both biological and thermochemical processing with production of fuels, power, and/or animal feed protein – are compared with respect to process efficiency, environmental impact – including petroleum use, greenhouse gas (GHG) emissions, and water use–and economic profi tability.	-	Qualitative description of fourteen technology biomass refining scenarios.	-
Larson E D.	2006	A review of life-cycle analysis studies on liquid biofuel systems for the transport sector.	Energy for sustainable development.Volume 10, issue 2, 109-126	Review of LCA for conventional liquid biofuels and potential future liquid biofuels	sugar beet, wheat	-	-
Levasseur A, Lesage P, Margni M, Deschenes L, Samson R.	2010	Considering time in LCA: Dynamic LCA and its application to global warming impact assessments.	Environmental Science and Technology, 44, 3169-3174	A dynamic LCA approach is proposed to improve the accuracy of LCA by addressing the inconsistency of temporal assessment.	-	-	Dynamic LCA is applied to the US EPA LCA on renewable fuels, which compares the life cycle greenhouse gas emissions of different biofuels with fossil fuels including land-use change emissions.
Levasseur A, Brandão M, Lesage P, Margni M, Pennington D, Clift R, Samson R	2012	Valuing temporary carbon storage	Nature climate change, Vol 2, January 2012	Temporary carbon-sequestration and carbon-storage projects help offset fossil-fuel carbon emissions. The paper comments and discusses how effective are they.	-	-	The paper discusses about temporaray carbon storage. It is more than a technological detail: it is becoming a significant and contentious issue in the development of standards and guidelines for carbon-footprint calculation.
Luo L, Van der Voet E, Huppes G.	2009	An energy analysis of ethanol from cellulosic feedstock-corn stover	renewable and sustainable energy reviews, 13, 2003-2011.	-	Corn stover	-	-
Mittal J. P., Dhawan K. C., Thyagraj C. R.	1991	Energy scenario of castor crop under dryland agriculture of Andhra Pradesh	Energy Conversion Management, Vol. 32, No. 5, pp. 425-430	Estimate the energy needs of castor oil seed crop of dryland agriculture. Two experiments were conducted with three tillage treatments under two farming systems (bullock-animal and tractor farming).	Details for growing castor crop under bullock and tractor framing.	-	-

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Niederl A, Narodoslawsky M	2004	LCA study of biodiesel from tallow and used vegetable oil	Institute for resource efficient and sustainable systems "Process evaluation"	Compare the environmental impacts of biodiesel from tallow and used vegetable oil with fossil diesel.	Tallow and used vegetable oil.	Transesterification process.	Glycerol is a marketable co-product of the biodiesel transesterification process. Therefore, mass allocation can be justified. Due to similar prices for biodiesel and glycerol, economic allocation would only yield a slightly changed picture.
Piemonte V	2011	Wood Residues as Raw Material for Biorefinery Systems: LCA Case Study on Bioethanol and Electricity Production	Journal of polymers and the environment	This paper focuses on a biorefinery concept and in particular on the bioethanol production from wood residues. In order to evaluate the environmental reliability of the system under study, the biorefinery plant (producing bioethanol and electricity from wood residues) was compared, by using the LCA methodology, to both conventional refinery system (producing light fuel oil and electricity from petroleum) and biorefinery plant based on corn feedstock producing the same goods.	-	-	Interesting considerations about LUC emissions effect on biorefinery sustainability are reported.
Reijnders L, Huijbregts M A J	2011	Nitrous oxide emissions from liquid biofuel production in life cycle assessment	Current Opinion in Environmental Sustainability 2011, 3:432–437	The contribution of N2O to the greenhouse balance of biofuels depends on a number of factors, including cropping system, climate, reference land use system, allocation strategy, and time horizon considered. This paper discusses these critical factors, compares the relative contribution of N2O to the overall greenhouse gas balance of biofuels and specifies reduction options for N2O emissions linked to the crop cultivation stage of the biofuel life cycle.	-	-	This work discusses N2O emissions models treating some critical factors as cropping system, climate, refrence land use system, allocation strategy and time horizon.
Renouf M. A., Pagan R. J., Wegener M. K.	2010	LCA of Australian sugarcane products with a focus on cane processing	Int J LCA, online : 30 September 2010	Generate LCA results for products produced from Australian sugarcane—raw sugar, molasses, electricity (from bagasse combustion), and ethanol (from molasses). It focuses on cane processing in sugar mills and is a companion to the previous work focused on cane growing.	Sugarcane production (up to the delivery of harvested cane to the sugar mill) is reported in a previous Renouf paper which has a focus on cane growing.	Three models of cane processing are considered: (1) conventional sugar mill, (2) upgraded sugar mill with cogeneration and (3) upgraded sugar mill with cogeneration and ethanol production from molsasses.	This work also examines the preferred approach for assigning impacts to the multiple products from cane processing (allocation), and the influence that variability in cane growing has on the results.

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Sarlos G., Haldi P. A., Verstraete P.	2003	Systèmes énergétiques - Offre et demande d'énergie: méthode d'analyse	EPFL - PPUR, Traité de Génie Civil Volume 21	This book explains the basis for analysis, modeling, design, dimensioning and management systems and energy infrastructures.	-	-	It gives formulas to estimate gross calorific value of lignocellulosic materials and materials in general (with a carbon content inferior of 80%). It gives data about carbon content in cellulose, hemicellulose and lignin.
Schaidle J A, Moline C J, Savage E	2011	Biorefinery Sustainability Assessment	Environmental Progress & Sustainable Energy (Vol.30, No.4) DOI 10.1002/ep	This article presents a comparative sustainability assessment (environmental, economic and social metrics) of three biorefineries that produce liquid fuels used in current infrastructure: (1) biochemical production of ethanol from grain and (2) from cellulosic feedstocks and (3) thermochemical production of Fischer-Tropsch diesel from biomass-derived syngas. The used metrics were determined from values reported in literature for a variety of different process designs and feedstocks. The Analytic Hierarchy Process (AHP) methodology is used as a decision-making tool that can incorporate the many competing factors involved in answering a complex question.	-	Three processes are considered: (1) biochemical production of ethanol from grain and (2) from cellulosic feedstocks and (3) thermochemical production of Fischer-Tropsch diesel from biomass-derived syngas.	-
Schmidt J H	2008	System delimitation in agricultural consequential LCA. Outline of methodology and illustrative case study of wheat in Denmark	Int J Life Cycle Assess (2008) 13:350–364	This paper presents a framework for defining system boundaries in consequential agricultural LCA. The framework is applied to an illustrative case study; LCA of increased demand for wheat in Denmark. The aim of the LCA screening is to facilitate the application of the proposed methodology and to illustrate that there are different ways to meet increased demand for agricultural products and that the environmental impact from these different ways vary significantly.	-	-	A framework for definig system boundaries in consequential agriculturale LCA is presented. If a full quantification of the methodology presented in this article is assessed as being inappropriate, it is recommended to describe the most likely routes in a qualitative way. This approach facilitates the making of reservations to the conclusions drawn on the basis of an attributional LCA.

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Searchinger T, Heimlich R, Houghton R A, Dong F, Elobeid A, Fabiosa J, Tokgoz S, Hayes D, Yu T	2008	Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change	SCIENCE VOL 319	This paper estimates land-use cahnges using a worldwide model to project increases in cropland in all major temperate and sugar crops by country or region in response to a possible increase in US corn ethanol of 56 billion liters above projected levels for 2016.	-	-	The paper focuses on land-use change issue. This study highlights the value of biofuels from waste products because they can avoid land-use change and its emissions. To avoid land use change altogether, biofuels must use carbon that would reenter the atmosphere without doing useful work that needs to be replaced, for example, municipal waste, crop waste, and fall grass harvests from reserve lands. Algae grown in the desert or feedstocks produced on lands that generate little carbon today might also keep land-use change emissions low, but the ability to produce biofuel feedstocks abundantly on unproductive lands remains questionable.
Sendich E D, Dale B E	2009	Environmental and economic analysis of the fully integrated biorefinery	GCB Bioenergy (2009) 1, 331–345	This paper describes a new research tool, the Biorefinery and Farm Integration Tool (BFIT) in which the production of fuel ethanol from cellulosic biomass is integrated with crop and animal (agricultural) production models. Uniting these three subsystems in a single combined model has allowed, for the first time, basic environmental and economic analysis of biomass production, possible secondary products, fertilizer production, and bioenergy production across various regions of the United States. Sensitivity analysis revealed three parameters with the greatest influence on the overall system outcomes simulated in BFIT. These are: biorefinery size, switchgrass yield, and biomass farm-gate selling price.	-	Three influencing parameters are discussed: biorefinery size, biomass yield and biomass farm-gate selling price.	-

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SenterNovem	2008	Participative LCA on biofuels	-	To communicate the environmental impacts of biomass-based fuels as compared to fossil diesel and gasoline with various stakeholders. To actively involve the stakeholders in the whole process of LCA, including the determination of the input parameters.	Wheat, rapeseed.	-	-
Sheehan J, Camobreco V, Duffield J, Graboski M, Shapouri H	1998	Life cycle inventory of biodiesel and petroleum for use in an urban bus	National Renewable Energy Laboratory, Golden	Compare the use of soybean based biodiesel in buses with petroleum based biodiesel use.	Soybean	-	-
Tan R, Culaba A	-	Life-cycle assessment of conventional and alternative fuels for road vehicles	-	Assess the environmental impacts of biofuels and natural gas derivatives relative to conventional automotive fuels.	Cellulosic agricultural waste and coconut.	Bioethanol from cellulosic agricultural waste and biodiesel from coconut oil	-
Uihlein A., Schebek L.	2009	Environmental impacts of a lignocellulose feedstock biorefinery system : An assessment	Biomass and bioenergy 33 (2009) 793-802	LCA of a lignocellulose feedstock biorefinery system and compared it to conventional product alternatives.	Straw	6 alternatives: basic biorefinery without acid and heat recoveries (1), optimised with acid recovery (2), optimised with heat recovery (3), optimised with acid and heat recovery (4), lignin used to provide process heat (5) and lignin used to produce electricity (6). Inventory for biorefinery processes referred to 1000 kg straw input: electricity, hydrochloric acid, heat, water and hydrogen.	-
Wang M	2005	Updated energy and greenhouse gas emission results of fuel ethanol	Center for Transportation Research, Argonne	Compare the energy use and GHG emissions of corn based bioethanol and conventional gasoline	Corn	-	-
Whitaker M., Health G.	2009	LCA of the use of Jatropha Biodiesel in Indian Locomotives	NREL - U.S. Department of Energy	Evaluation of the production of conventional petroleum diesel and the production of biodiesel from Jatropha for use in the operation of Indian Railways locomotives.	Cultivation of Jatropha trees and operation of the plantation including fertilizer use, irrigation water, electricity, and diesel fuel, along with parameters such as the rate of N_2O release from nitrogen fertilizer.	Jatropha oil extraction process (solvent extraction process with 91% extraction efficiency). The study focuses on base-catalyzed transesterification of Jatropha oil to biodiesel.	N_2O emission factor accounts for direct emissions from a variety of organic and synthetic nitrogen fertilizers; the emission factor does not include secondarys or indirect emission sources of N_2O.

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Wu M, Wu Y, Wang M.	2006	Energy and emission benefits of alternative transportation liquid fuels dervied from switchgrass: a fuel life cycle assessment.	Biotechnology progress, 22, 1012-1024.	Assess the environmental impacts of ethanol produced from corn or switchgrass	Switchgrass , corn.	-	-
You F, Tao L, Graziano D J, Snyder S W	2011	Optimal Design of Sustainable Cellulosic Biofuel Supply Chains: Multiobjective Optimization Coupled with Life Cycle Assessment and Input–Output Analysis	American Institute of Chemical Engineers Journal, 00: 000–000	This article addresses the optimal design and planning of cellulosic ethanol supply chains under economic, environmental, and social objectives. The economic objective is measured by the total annualized cost, the environmental objective is measured by the life cycle greenhouse gas emissions, and the social objective is measured by the number of accrued local jobs.	-	-	LCA is integrated with multiobjective optimization approach. A field-to-wheel approach is used to assess the GHG impact.