LCA DATA GAPS IN FEEDSTOCKS OF BIOBASED PLASTICS

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ABSTRACT

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Bioplastics are a growing field, but with their expansion comes unique environmental issues associated with the cultivation and processing of feedstocks. Availability of appropriate, high quality data is a problem in life cycle assessment (LCA) of biopolymers and other biobased materials that limits the accuracy and usefulness of study results. It is therefore critical that these data gaps be closed. In order to determine what data is needed to close these gaps, this study reviews currently available life cycle inventory data for biobased polymer feedstocks, and assesses the data quality for the selected feedstocks of corn, sugarcane, and soy. Life cycle inventory databases and relevant publications were searched for appropriate data, and the results collected into a summary table. The quality review was conducted using a pedigree matrix type scoring system which was adapted from the ILCD handbook, and an overall quality score for each dataset was calculated based on the matrix scores. A total of 287 datasets were collected during the review for a total of 22 different feedstocks. The majority of these datasets are from Europe and the USA, with the majority of Asia, the Middle East, and Africa having very limited data available. From the quality analysis, it was determined that more datasets that capture regional variations in crop cultivation are needed, as well as more data on land use change. Additionally, for the processing phase of production there is a need for more recent and better documented data.

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1. INTRODUCTION

Recently, the public and government organizations have become increasingly aware of the sustainability challenges faced by the world. Greenhouse gases (GHGs) in particular, and their link to both global warming and the consumption of fossil fuels, have garnered substantial attention. With this increased awareness comes the opportunity for the academic community to positively impact the decisions that are made and the way business is conducted. However, in order to make sound recommendations, reliable and high quality tools are necessary to objectively evaluate situations and assess the best course of action.

Life Cycle Assessment (LCA) is an objective method of evaluating the sustainability of a system and assessing its impacts on the environment [1]. Finding a sustainable solution to a problem is never a simple task. Often each option being considered has its own set of advantages and disadvantages which must be weighed and understood. One of the strengths of LCA is its ability to quantify and categorize the individual impacts of a system and facilitate comparison. It is an effective tool for this purpose because of the level of detail and complexity it is able to convey; but like any method it has its limitations. It has been called "a vital and powerful decision support tool, complementing other methods, which are equally necessary to help effectively and efficiently make consumption and production more sustainable" [2].

The quality of information available from an LCA study is largely limited by the quality and completeness of the data on which it is built. Without complete, high quality data, one cannot be confident that the results of an LCA study accurately represent the situation. Therefore, the quality of the data used in a study affects the quality of the recommendations that come out of said study [2].

This problem is exacerbated by the fact that LCA studies often require the inclusion of an expansive amount of information to achieve their goals. For example, if one wants to accurately describe the environmental impacts of a plastic container, it is necessary to have data not only about the material and production process, but also about the machinery being used, the power source being used, and a multitude of other inputs. As Álvarez-Chávez puts it: "Because of the myriad issues to consider, it can be very challenging to determine which plastic materials are safest and healthiest for workers, consumers, and the environment" [3]. Because of the necessity of including such a large scope of information, it is a common practice for LCA practitioners to draw on data from many sources. It may be impossible or impractical to generate primary data for every aspect of the system covered by a study. To solve this problem, previously generated data from literature is often used to fill in the gaps in information.

This means that a bank of data to draw from is extremely useful if not outright necessary for most LCA studies; this presents a particular challenge to practitioners when attempting to conduct an LCA on a system that utilizes newer technologies. New technologies are particularly vulnerable to the problem of low quality data. The relatively short time they have been in existence means that there is a significantly smaller body of research from which to pull, and subsequently one is often forced to settle for data that is less than ideal.

Such is the case with data for biopolymers. Interest in biopolymers is increasing because of their potential to address the issue of fossil fuel depletion and mitigate greenhouse gas emissions [4]. An article in May 2012 predicted that the demand for polylactic acid (PLA) is expected to increase by 20% per year [5]. Production of biopolymers is expanding in response to this increased demand. However, bio-based plastics bring with them their own set of problems. In a 2012 comparative analysis Álvarez-Chávez et al state "A bio-based plastic is not necessarily a sustainable plastic; this depends on a variety of issues, including the source material, production process, and how the material is managed at the end of its useful life" [3]. In other words, in order to correctly asses a biopolymer's environmental footprint one must have accurate and representative data about many aspects of the polymer's life cycle, including the production of that polymer. A particular challenge of LCA studies of biopolymers is understanding the impact of growing the polymer feedstock since, as discussed by Nemecek et al., "Environmental impact data for crops in the literature and the LCA databases are scarce" [6].

This means LCA data for biopolymers must be obtained; but what type of data should be collected? Before more information can be sought out, it is necessary to identify what types of data are most needed. Identifying critical data gaps for LCA of biopolymers will provide a foundation for future research. By indicating what areas are weak in data availability, researchers can identify the types of data that should be focused on when collecting primary data. If researchers are conducting a study on PLA, for example, they may choose to focus their efforts on the collection of water usage data instead of another type such as pesticide use, depending on which area has a more significant data gap, and therefore less surrogate data to pull from. Understanding the quality and completeness of currently available data also has the potential to clarify the strengths and limitations of existing studies that use this data, as it may shed new light on how representative the study is of the system it is trying to model.

The first step in the quest to solve data issues in LCA is addressed by van der Voet et al. in a review of the state of LCA for the related field of biofuels: "The way forward to remedy data problems is clear: identify data needs, collect more and better data and make them accessible" [7]. A review of the state of currently available LCA data is the first step to improving the quantity and quality of available data, because without being aware of what is already published it would be impossible to know where future efforts in data acquisition should be focused. The goal of this project is to identify the critical data gaps present in LCA data for biopolymer feedstocks in order to illuminate the next step in the path to a more sustainable bioplastic.

2. LITERATURE REVIEW

The importance of high quality data for LCA has been well documented. The International Organization for Standardization (ISO) devotes several sections of their guide for conducting an LCA to data quality requirements, and outlines several tools and checks that a practitioner may use to assess the quality of their data [2]. Additionally, several Life Cycle Inventory (LCI) databases have their own methods of evaluating data. In a 2011 article in the International Journal of Life Cycle Assessment, Cooper et al. [8]explore the strengths and weaknesses of the current commonly used methods for assessing data quality. These methods vary in the way they report data quality. Ecoinvent and the ILCD handbook utilize a numerical scoring method where data can be judged to fall anywhere from 1 (very good) to 5 (very bad). In contrast, the LCA Commons database divides data into two categories, A and B, where A is high quality data and B is low quality data. This method was developed as a way to distinguish between data quality without the use of a numeric scoring system, which has been criticized as being difficult to interpret. However, they all address the data quality issues that are defined by ISO. In fact, the article concludes that "The strengths of data quality analysis methods lie in the consideration of the data quality aspects specified by the ISO standards" [8].

ISO names several areas that should be considered when evaluating data quality. Specifically they are: time related coverage, geographical coverage, technological coverage, precision (measure of the variability of the data values), completeness, representativeness, consistency, reproducibility, source of data, and uncertainty of information. Of the items on the list, the first four are better documented and explored in terms of their effect on the outcomes of LCA studies.

When one thinks of examples of gaps in LCA data for agricultural products, the first thing that comes to mind is an instance where there is no data for a certain process, or no data for a certain crop. However gaps in data availability also occur between technologies, geographic areas, and as methods or conditions change over time. Even a seemingly simple example where only the region of production is varied can have hidden depths. This is because agricultural methods can vary significantly by region, even for the same crops; and this variation in turn can create large differences in the environmental impacts of these different systems. For example, soybeans may be grown using a traditional till, irrigated system in one region and a no-till, non-irrigated system in another region. In this situation, the fossil fuel and water usage could both potentially be significantly greater for the first system. This is supported by information from Kim and Dale in a 2009 report on the sustainability and competitive position of biobased chemicals. They found that "local variation in GHG emissions of platform chemicals [ethanol and soy biodiesel] are significant due to tillage practices, irrigation, soil types and fuel consumption" [9].

It is therefore necessary for an LCA practitioner to consider and adjust based on the difference between both the geographical and the technological coverage of the dataset they are using in a situation such as this. However, this is more easily said than done. Variation between geographical areas can be complex and difficult to model. One study that tracked water consumption in ethanol production from corn in 81 different watersheds in Minnesota found significant variation in the range of water consumption between watersheds. The study included the use of both irrigation water and process water. The range in the amount of water used to produce 1 L ethanol was found to be 3 – 181 L in a watershed in central Minnesota. Contrastingly, ethanol produced in a watershed in the south of the state had a much smaller range in the amount of water used. Farms and production facilities based in the southern watershed used only 3 - 8 L of water to produce 1 L ethanol from corn [10]. This demonstrates that the issue of geographical correlation is not as simple as one might assume. LCA practitioners are often compelled to use data from a different region than the one under study. Generally, an effort is made to use data from a region with similar geography and practices, but in this case large variation was found within a single region that was utilizing relatively uniform technology. This suggests not only that it is quite difficult to predict a correlation between regions, but also that even data from a slightly different part of the same region may not be an accurate substitute.

This issue of hidden complexity is not isolated to a single incident or a single input. There are cases of disagreement among researchers about the amounts of fossil fuels that are used in the production of biopolymer feedstocks. A study by Reijnders and Huijbregts in 2007 concluded that fossil fuels are most often used as a power source in the production of palm oil based biodiesel, and generally represent 75% of the fuels used in this process. This assumption is not consistent with information from Malaysia and Indonesia which asserts that the main source of energy for processing of palm oil is from combustion of palm residues, mainly shells and fibers, and that as little as 2% of process energy comes from fossil fuels [11]. This is just one example of an instance where uncertainty surrounding the technology being used sparked debate about what data should be used to model a system, but it is a significant one. The variation of fossil fuel use in turn affects the greenhouse gas emissions of the system, in this case by as much as 21% [11].

Another example surrounding the uncertainty of greenhouse gas emissions in relation to biomass production springs from the issue of precision. In an article about sampling error in US crop surveys, Cooper et al. presents this example: "consider…a comparison of the life cycles of a conventional fuel and a biofuel in which the conventional fuel has an estimated mean greenhouse gas emission of 47 grams of carbon dioxide equivalent per mega joule (g CO2eq/MJ) and the biofuel of 38 g CO2eq/MJ. Without consideration of variability, the biofuel is found superior to the conventional fuel" [12]. However, the article goes on to explain how the relative standard errors (RSE) of the data these means are based on affect the viability of this assertion. "Thus, without knowledge of the error and sample sizes, the comparison of greenhouse gas emissions can be meaningless" [12]. Although this example is theoretical, the paper presents a strong case for caution when making these comparisons, and illustrates the effect data precision has on study results.

Recently, more attention has been focused on the impacts of agriculture that are harder to measure, and therefore for which data are more difficult to obtain. The inclusion of these impacts has the potential to significantly change the results of an LCA study, and they bring with them additional challenges in data quality that researchers must overcome. In a study about the effect of land use change (LUC) on GHG emissions, Piemonte et al. point out the effects LUC has on the environmental impact of a bioplastic: "If, on one hand, the bioplastics can save in terms of fossil resources and GHG emissions, on the other, agricultural biomass production might cause adverse environmental effects such as soil erosion, eutrophication of ground and surface waters, or fragmentation of habitats" [4].

There is generally agreement that these types of impacts are important to understanding the true environmental effects of biopolymers. Emissions from LUC, both direct and indirect, may be especially important in understanding local and regional effects of biomass production, but it is difficult to measure and quantify them, so they are often excluded for practical reasons [13]. The effects of indirect land use change (displacing previous agricultural production to other land) have been estimated to span a large range of values, varying from a small effect (10 kg CO2-eq/GJ ethanol) to one that is several times greater than the life cycle emissions of CO2 for gasoline (340 kg CO2-eq/GJ ethanol) for the same feedstock [13]. The latter is obviously a concern, since one of the main attributes of biopolymers that make them attractive is their ability to mitigate GHG emissions. These data gaps impact the ability of LCA studies to accurately describe a system. As Weiss et al conclude in "A Review of the Environmental Impacts of Biobased Materials," "The variability in the results of life cycle assessment studies highlights the difficulties in drawing general conclusions" [13]. Certainly, there are many sources of variability and many reasons why LCA results vary. However, it is just as certain that the availability of appropriate data is one of these sources.

3. METHODS

In order to identify critical data gaps for bio-based plastics, a review of currently available data was conducted. Information was collected from the LCA databases Ecoinvent, GaBi-PE (Ecoinvent data modified by GaBi), USLCI, LCA Food DK, and LCA Commons. The software programs SimaPro and GaBi were used to access all of these databases except LCA Commons, which has not been integrated into the software programs. The websites of LCA Food DK and USLCI were also searched for information. Additionally, publications were searched for relevant data that had not yet been integrated into the databases. Since it is not feasible to search all publications, a selection of publications was chosen based on the likelihood that they would contain relevant information. Table 1 contains the list of publications and timeframes searched.

Table 1 - List of publications searched

Publication Name	Time Frame
Journal of Cleaner Production	2013-2005
International Journal of LCA	2012-2000
Bioresource Technology	2012-2005
Biomass and Bioenergy	2012-2005
Environmental Science and Technology	Selected
Packaging Technology and Science	Selected
Journal of Industrial Ecology	2012-2008
Sustainability	2012-2005
Science	2012-2008
PNAS	2012-2005

All data pertaining to feedstocks that are viable for use in the production of bio-based plastics were considered in the search. These data relate to many aspects of bioplastic production, including raw agricultural feedstocks (i.e. corn, soybeans) through processing steps (i.e. sugar or oil), platform chemical production (i.e. ethanol and biodiesel), and polymer production. The relevant data sources were collected into a summary table. The table organizes data sources by category (raw agricultural, processed agricultural, wood, chemical, and polymer), and feedstock material.

The table also captures other information about the data that would be of interest to a practitioner who is considering using one of the datasets, including where the data is available, the details of the study (if applicable), the year(s) of publication, and the region to which the data pertains. The data were also checked against common agricultural inputs and the results catalogued in the summary table. A “1” in the column of the indicated input means that the dataset in that row contains a flow for that input. For example, if a soy data file has a “1” in the column marked “tillage” that means the process of tilling the field and associated inputs are included in that data file. In this way, a preliminary completeness check was conducted on all the data collected in the summary table.

Because of the large number of data sources amassed, it was necessary to narrow the focus of the project in order to conduct a deeper analysis of the data. Corn, sugarcane, and soy were the feedstocks selected to be analyzed in more detail. These feedstocks were chosen based on their current use as biopolymer feedstocks. The first step was to conduct a completeness check on the available data for these crops. Information from ISO 14044 and the ILCD handbook was used to inform this process [2, 14]. The completeness check involved searching each data file in detail and noting what inputs were considered and, when possible, how they were accounted for. For the database files, this meant looking through the data directly, at the flow level. For the data contained in journal articles, it involved searching for information within the article and looking up data source information from the references. An effort was made to include all significant input categories for these feedstocks in the check. The input categories that were included in this check are as follows: carbon sequestration, seed production, soil preparation, transport of materials to the farm, fuel used on the field, power for farm activities, machines, machine shelter, sowing, tilling, fertilizer, pesticide, herbicide, lime, crop residue management, irrigation, harvesting, grain drying, direct field emissions, crop storage, land occupation, and land use change.

Additionally, several inputs relating to biomass processing were considered in the completeness check. These were considered separately, so some data files underwent two completeness checks. The processing inputs include: loading, transportation of the crop to the refinery, process chemicals, waste treatment, infrastructure, facility land use, processing machinery, process energy, extraction and milling, refining, process water, fermentation, and drying. Not all inputs were relevant to all data sets. For example, a study that only considered GHG emissions would not include water use. It was noted in the completeness check results when an input was specifically excluded from a study because it was not within the study scope.

Next, a pedigree matrix scoring system was used to evaluate the data sets for corn, soy, and sugarcane. The data were evaluated on their technological, geographical, and temporal representativeness on a scale from 1-5. When information was available, data uncertainty was also considered in the evaluation. From this evaluation and the completeness evaluation, a Data Quality Rating (DQR) was calculated. Agricultural data was considered separate from processing data. Some datasets therefore have two DQRs, one for agricultural data quality, and one for processing data quality. The evaluation criteria and the formula used to calculate the overall score are were adapted from the ILCD Handbook and van der Berg et al. [14, 15]. Table 2 explains the different categories considered in the evaluation of the data, and Tables 3 and 4 explain the ranking of the quality ratings [14, 15].

It was necessary to consider the quality ranking recommendations of both the ILCD and van der Berg et al. in order to complete a consistent analysis. The ILCD rankings are described in general terms, and do not have category-specific requirements. Therefore, the criteria put forth by van der Berg et al. were used to supplement the ILCD recommendations. Specific category ranking requirements from van der Berg et al. were applied. For example, data that was less than three years older than the study date was given a score of 1 in temporal correlation. It should be noted that the category "Reliability" from van der Berg et al. and the category "Precision/Uncertainty" from the ILCD handbook are equivalent. The ILCD handbook also includes another evaluation category, Methodological Appropriateness and Consistency, which was not used in this evaluation. This category was excluded because it is dependent on the goal and scope of the intended application of the dataset.

Table 2 – Definition of evaluation categories adapted from the ILCD Handbook

Indicator / Component	Definition / Comment
Technological Representativeness (TeR)	"Degree to which the data set reflects the true population of interest regarding technology, including for included background data sets, if any."
Geographical Representativeness (GR)	"Degree to which the data set reflects the true population of interest regarding geography, including for included background data sets, if any." Comment: i.e. of the given location / site, region, country, market, continent, etc.
Time Related Representativeness (TiR)	"Degree to which the data set reflects the true population of interest regarding time/ age of data, including for included background data sets, if any." Comment: i.e. of the given year (and - if applicable – of intra-annual and intra-daily differences).
Completeness (C)	"Share of (elementary) flows that are quantitatively included in the inventory. Note that for product and waste flows this needs to be judged on a system's level." Comment: i.e. degree of coverage of environmental impact i.e. used cut-off criteria.
Precision / uncertainty (P)	Measure of the variability of the data values for each data expressed (e.g. low variance = high precision). Note that for product and waste flows this needs to be judged on a system level.

Table 3 –Quality Rating Definitions adapted from the ILCD Handbook

Quality Level	Quality Rating	Definition
Very Good	1	"Meets the criterion to a very high degree, having no relevant need for improvement. This is to be judged in view of the criterion's contribution to the data set's potential overall environmental Impact and in comparison to a hypothetical ideal data quality."
Good	2	"Meets the criterion to a high degree, having little yet significant need for improvement. This is to be judged in view of the criterion's contribution to the data set's potential overall environmental Impact and in comparison to a hypothetical ideal data quality."
Fair	3	"Meets the criterion to still sufficient degree, having the need for improvement. This is to be judged in view of the criterion's contribution to the data set's potential overall environmental Impact and in comparison to a hypothetical ideal data quality."
Poor	4	"Does not meet the criterion to a sufficient degree, having the need for relevant improvement. This is to be judged in view of the criterion's contribution to the data set's potential overall environmental Impact and in comparison to a hypothetical ideal data quality."
Very Poor	5	"Does not at all meet the criterion, having the need for very substantial improvement. This is to be judged in view of the criterion's contribution to the data set's potential overall environmental Impact and in comparison to a hypothetical ideal data quality."
Not Applicable	0	Criteria could not be applied

Table 4 –Pedigree Matrix Data Quality Rating Level Definitions adapted from van der Berg et al.

Indicator Score	1	2	3	4	5
Reliability	Verified data based on measurements	Verified data partly based on assumptions or non-verified data based on measurements	Non-verified data partly based on assumptions	Qualified Estimate (e.g. by industrial expert)	Non-qualified estimate
Completeness	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations	Representative data from a smaller number of sites but for adequate periods	Representative data from adequate number of sites but from shorter periods	Representative data but from a smaller number of sites and shorter periods or incomplete data from an adequate number of sites and periods	Representativeness unknown or incomplete data from a smaller number of sites and/or from shorter periods
Temporal Correlation	Less than three years difference to year of study	Less than six years difference	Less than 10 years difference	Less than 15 years difference	Age of data unknown or more than 15 years difference
Geographical Correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown area or area with very different production conditions
Technological Correlation	Data from enterprises, processes, and materials under study	Data for processes and materials under study but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials but same technology	Data on related processes or materials but different technology

Data was examined in the greatest detail possible when scoring each category since most datasets have multiple sources of information that can be of varying quality. These differences are accounted for by scoring each source of data and then resolving their respective scores into a single category score. Background process data were weighted less heavily when resolving scores, as were data that are not sensitive to a specific category. For example, using a US electricity mix for sugar production in Brazil is a significant difference because Brazilian sugarcane processing is generally powered by the burning of bagasse, a sugarcane co-product. This substitution therefore represents a significant technological difference. However, if US diesel tractor emissions were substituted for Brazilian diesel tractor emissions, the difference is not as significant since the technology is nearly identical.

Additionally, half scores were given to categories when deemed appropriate. For example, a dataset published in 2010 for which half of the relevant data was from 2009 (less than 3 years difference) and half was from 2005 (less than six years difference) would be given an overall score of 1.5 in the category of temporal correlation. In order to ensure transparency, each score is reported with its individual justification.

Equation 1 was used to calculate the DQR for each dataset [14]. Note that the lowest criteria score is weighted in the formula by five-fold. This is done because the weakest quality indicator significantly weakens the overall quality of the dataset being evaluated [14]. The Precision (P) quality indicator was only included in the calculation of the DQR for Ecoinvent data. This was necessary due to the lack of information about precision for most datasets. When evaluating the precision of the Ecoinvent data, the Ecoinvent uncertainty scoring criteria were used to interpret the uncertainty scores for each flow [16]. Then, a single uncertainty score was chosen for the file based on this interpretation. An explanation of these criteria can be found in Appendix A.

A dataset with DQR less than or equal to 1.6 is considered high quality, while a dataset with a DQR between 1.6 and 3 is considered to be of basic quality. Any dataset with a DQR between 3 and 4 is considered to be an estimate [14].

Equation 1 – Data Quality Rating Formula and Definitions from the ILCD Handbook

$$DQR = \frac{TeR + GR + TiR + C + P + M + (X_W*4)}{i + 4}$$

DQR: Data Quality Rating of the LCI data set

TeR, GR, TiR, C, P, M: see table 2

X_W: weakest quality level obtained (i.e. highest numeric value) among the data quality indicators

i: number of applicable data quality indicators

4. RESULTS AND DISCUSSION

Data Availability

The summary table containing the details of all the collected datasets can be seen in Appendix F. Table 5 describes the type and number of entries it contains.

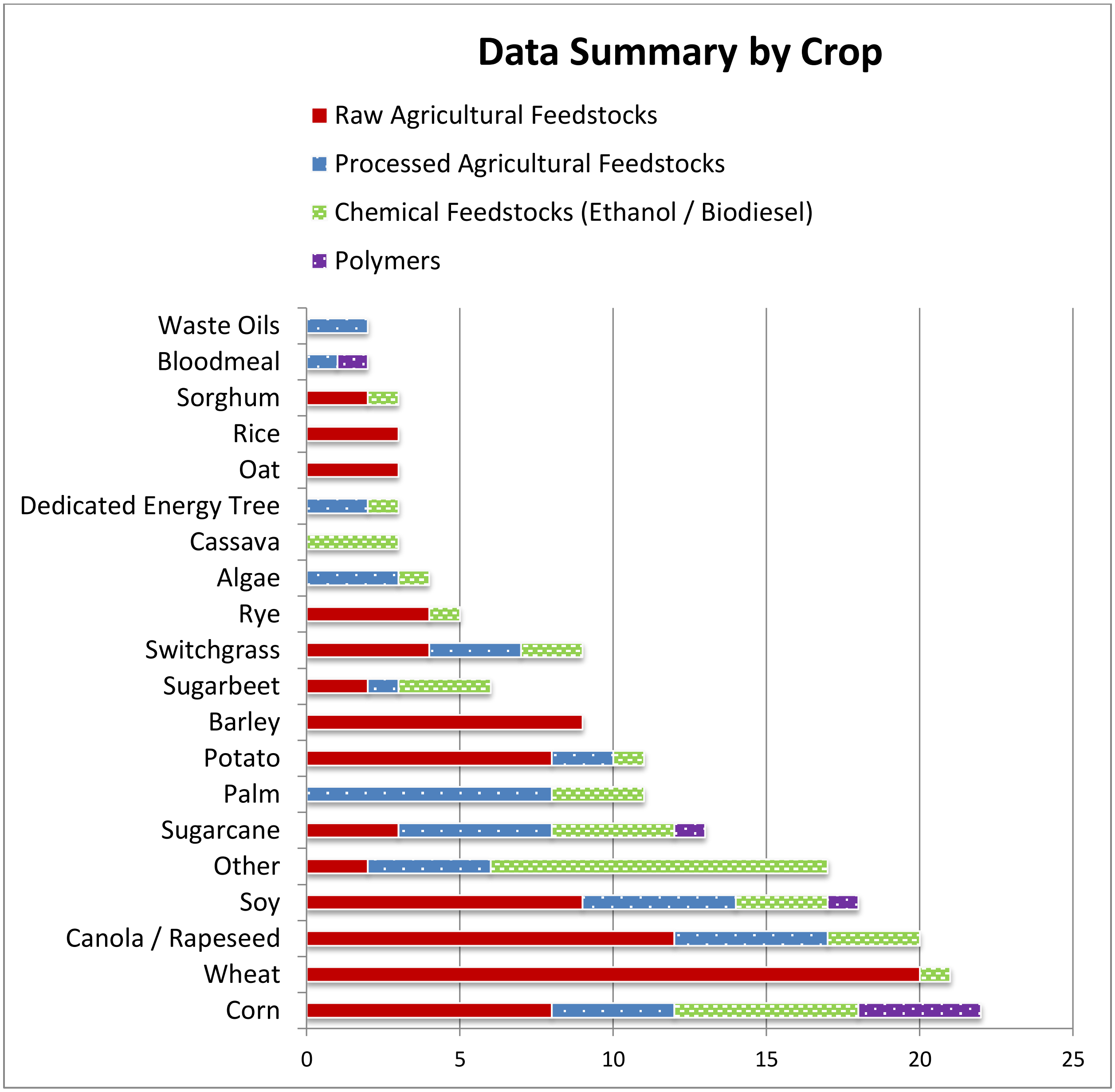
Table 5 – Quantity and type of data collected

Feedstock:	Total	Raw Agricultural Feedstocks	Processed Agricultural Feedstocks	Chemical Feedstocks (Ethanol/Biodiesel)	Polymers
Wood	60	0	54	6	0
Agricultural Residues	42	21	15	6	0
Corn	22	8	4	6	4
Wheat	21	20	0	1	0
Canola / Rapeseed	20	12	5	3	0
Soy	18	9	5	3	1
Other	17	2	4	11	0
Sugarcane	13	3	5	4	1
Palm	11	0	8	3	0
Potato	11	8	2	1	0
Barley	9	9	0	0	0
Sugarbeet	6	2	1	3	0
Switchgrass	9	4	3	2	0
Rye	5	4	0	1	0
Algae	4	0	3	1	0
Cassava	3	0	0	3	0
Dedicated Energy Tree	3	0	2	1	0
Oat	3	3	0	0	0
Rice	3	3	0		0
Sorghum	3	2	0	1	0
Blood meal	2	0	1	0	1
Waste Oils	2		2	0	0
Total	287	110	114	56	7

A total of 287 datasets were collected. It should be noted that in the case where one study contained multiple data sets each was counted individually. For example, one study compared US corn, UK sugar beet, and Australian sugarcane as producers of sugar for fermentation [17]. This study contained datasets for the cultivation of each of these crops, so three datasets were counted (one for sugarcane, one for corn, and one for sugar beet). Likewise, a study with both cultivation data and processing data for corn would contribute two datasets to the above count, one in the raw agricultural feedstock category and one in the processed agricultural feedstock category.

Of the 287 datasets found, 110 are for raw agricultural feedstocks, 114 are for processing of agricultural feedstocks, and 56 are for production of platform chemicals (mainly ethanol and biodiesel). Only seven datasets were found for the complete production of biopolymers. Figure 1 illustrates the number of datasets found for each crop. Each bar is a stacked total which represents the composition of the datasets for each crop by category. Wood and agricultural residues are excluded for reasons of convenience.

Figure 1: Summary of data collected by crop and category. For the interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.



The feedstock with the largest amount of datasets is wood, with a total of 60. However, this is largely because the same base data is available in multiple iterations. For example, data for board trimmings, sawdust, and woodchips in the US Pacific Northwest are all available and build off of the same base data. Therefore the high total is somewhat misleading. Agricultural Residue is the feedstock with the second highest amount of datasets collected at 42. This category includes things like corn stover, sugarcane bagasse, and wheat straw. This number is almost exclusively made up of Ecoinvent files. Ecoinvent has separated the data associated with the co-products of crop production into separate files, which means that for each crop Ecoinvent has data available, it also has data for the associated agricultural residue. Here, all of these residues are collected into a single category, which is why they are so numerous.

The crop with next largest amount of available data is corn (22), which is closely followed by wheat (21), rapeseed (20), and soy (18). Rapeseed and canola are grouped together because canola is a specific type of rapeseed suitable for human consumption [18]. The category "other" is mostly composed of data for ethanol from mixed feedstocks, which is available from Ecoinvent, and generic data for unspecified biomass. Sugarcane (13) has slightly less data available in relation to the other commodity crops commonly used to produce biopolymers. It should also be noted that no applicable datasets could be found for chitosan, despite the fact that a search was specifically conducted for this material. It should also be noted that over half (4 of 7) of the polymer datasets are based on corn.

The table and figure show that 8 datasets are available for raw corn. However, the 131 datasets available for corn from the US database LCA Commons are represented by a single entry in the summary table. This was done for reasons of practicality, since datasets in LCA Commons are state specific for a single harvest year. The short data collection time period is a quality issue, but 18 of the 131 data sets are aggregated over multiple years. These aggregated datasets are still state specific; LCA Commons does not have a file meant to represent averages for the entire USA. LCA Commons datasets are also included for soy (137), oats (12), rice (6), and wheat (155). They are represented in the table as described above.

Geographically, the data is skewed to Europe and North America with about 60% of the datasets (175 of 287) from one of the two regions (105 for Europe and 70 for North America). Additionally, about half of the European data (58 of 106) is for Switzerland. This is likely related to the fact that the Ecoinvent project is based in Switzerland. Likewise, nearly all of the North America data is for the USA. Only one of the 70 datasets for North America is explicitly for another country, a study about biodiesel production in Costa Rica. There are a number of USLCI datasets whose region is described in general as “North America” but these files are more reflective of the USA than of North American averages, being mainly built off of US data and modeling technology typical of the US. Figure 2 describes the regional breakdown of the data, while Table 6 gives a detailed breakdown of data availability by country.

Figure 2 – Geographical Distribution of Datasets

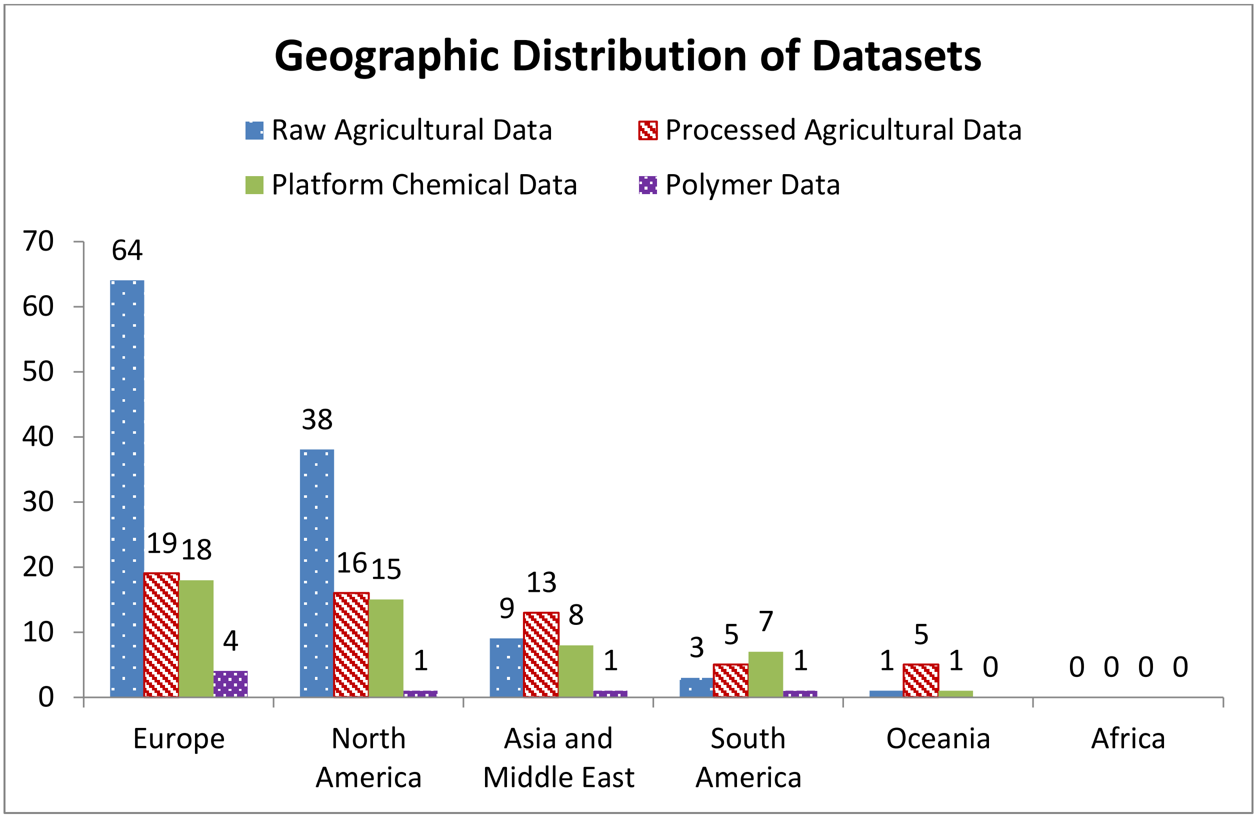


Table 6 – Data Availability by Country

Raw Agricultural Data	Count	Processed Agricultural Data	Count	Chemical Data	Count
Switzerland	39	USA	12	Switzerland	10
USA	29	Malaysia	7	Brazil	7
North America	9	Switzerland	7	North America	7
UK	7	Australia	4	USA	7
Denmark	7	Brazil	4	Europe	5
China	4	North America	4	Thailand	4
Germany	4	Europe	3	Unspecified	4
Unspecified	3	General	3	China	3
France	3	Germany	3	Sweden	2
India	3	UK	3	Argentina	1
Brazil	2	China	2	Australia	1
Europe	2	Denmark	2	Costa Rica	1
Spain	2	Argentina	1	Denmark	1
Average: USA and Europe	2	France	1	**Polymer Data**	**Count**
Argentina	1	India	1	USA	4
Australia	1	Indonesia	1	Brazil	1
Iran	1	New Zealand	1	Europe	1
Taiwan	1	Philippines	1	New Zealand	1
		Thailand	1		

As illustrated by Figure 2, the most obvious geographical data gap is that zero datasets were found that represent anywhere on the continent of Africa. Additionally, the category "Asia and the Middle East" covers a very large amount of area in theory, but in reality the datasets are focused on Southeast Asia and China. Only one dataset, potato production in Iran, breaks this pattern. The data designated Oceania is composed of one dataset for New Zealand with the remainder representing Australia. The South American data consists of entries from Brazil and Argentina, and is mostly for sugarcane and soybeans. In general, the geographical concentration of the datasets is in line with the demand for LCA data in each region. It makes sense that Europe and the USA, which both have strong policies in place that promote biofuels and LCI database projects, have more data available. Furthermore, the pattern of data concentration is consistent with areas that produce large amounts of commodities that are commonly used to produce biofuels and biopolymers.

A notable exclusion is that neither Canada nor Russia is represented in the datasets. The two largest countries in the world, Canada and Russia are both also major producers of grains that are commonly used to produce biodiesel and ethanol. Canada is the largest producer of canola, and Russia was the second largest producer of wheat in 2005 [19, 20]. The largest producer of wheat in 2005, India, is also under-represented in data availability [20]. There are four datasets for India but none of them are for wheat. Three are for agricultural residues suitable for cellulosic ethanol production (jute and kenaf stalks), and the fourth is for jatropha (an oilseed crop that can be grown on degraded land) [21].

Quality Analysis

A data quality evaluation was undertaken for cultivation of corn, soy, and sugarcane. The full results of this evaluation with score justifications can be seen in Appendix C. The processing data for these crops was evaluated separately, and results of this evaluation can be found in Appendix E. Full results of the completeness check for agricultural data are listed in Appendix B, and Appendix D contains the completeness check results for the processed agricultural data. It should be noted that some studies listed in the summary table for these crops were excluded from this evaluation. This was done if it was discovered during the completeness check that the data was taken from another source already under evaluation. For example, a sugarcane study that was built off the Ecoinvent file "sugarcane, at farm" would be excluded because that dataset was already included.

Figure 2 illustrates the composition of the corn DQRs by breaking them down into their constituent categories of completeness, uncertainty, and technological, geographical, and temporal representativeness. Figures 4 and 5 illustrate the same thing, but for sugarcane and soy, respectively. Tables 7, 8 and 9 match the identifiers in the figures with the corresponding dataset names for each feedstock.

Table 7 –Corn Dataset Names and Identifiers

Corn Dataset Name:	Identifier
Annual Report: Life Cycle Assessment to Improve the Sustainability and Competitive Position of Biobased Chemicals: A Local Approach	A
Grain maize organic, at farm (Ecoinvent)	B
Silage maize organic, at farm (Ecoinvent)	C
Corn grain, at harvest in (year), at farm 85-91% moisture (state) (LCA Commons)	D
Regional variations in GHG emissions of bio-based products in the United States - Corn based ethanol and soybean oil	E
Corn, at farm (Ecoinvent)	F
Grain maize IP, at farm (Ecoinvent)	G
Silage maize IP, at farm (Ecoinvent)	H
Measuring ecological impact of water consumption by bioethanol using life cycle impact assessment	I
Life cycle assessment of various cropping systems utilized for producing biofuels: Bioethanol and Biodiesel	J
Improvements in Life Cycle Energy Efficiency and Greenhouse Gas Emissions of Corn-Ethanol	K
LCA of cropping systems with different external input levels for energetic purposes	L
Corn, whole plant, at field (USLCI)	M
Corn, production average, US, 2022 (USLCI)	N

Figure 3 – Corn Data Quality Ratings and Component Scores by Dataset

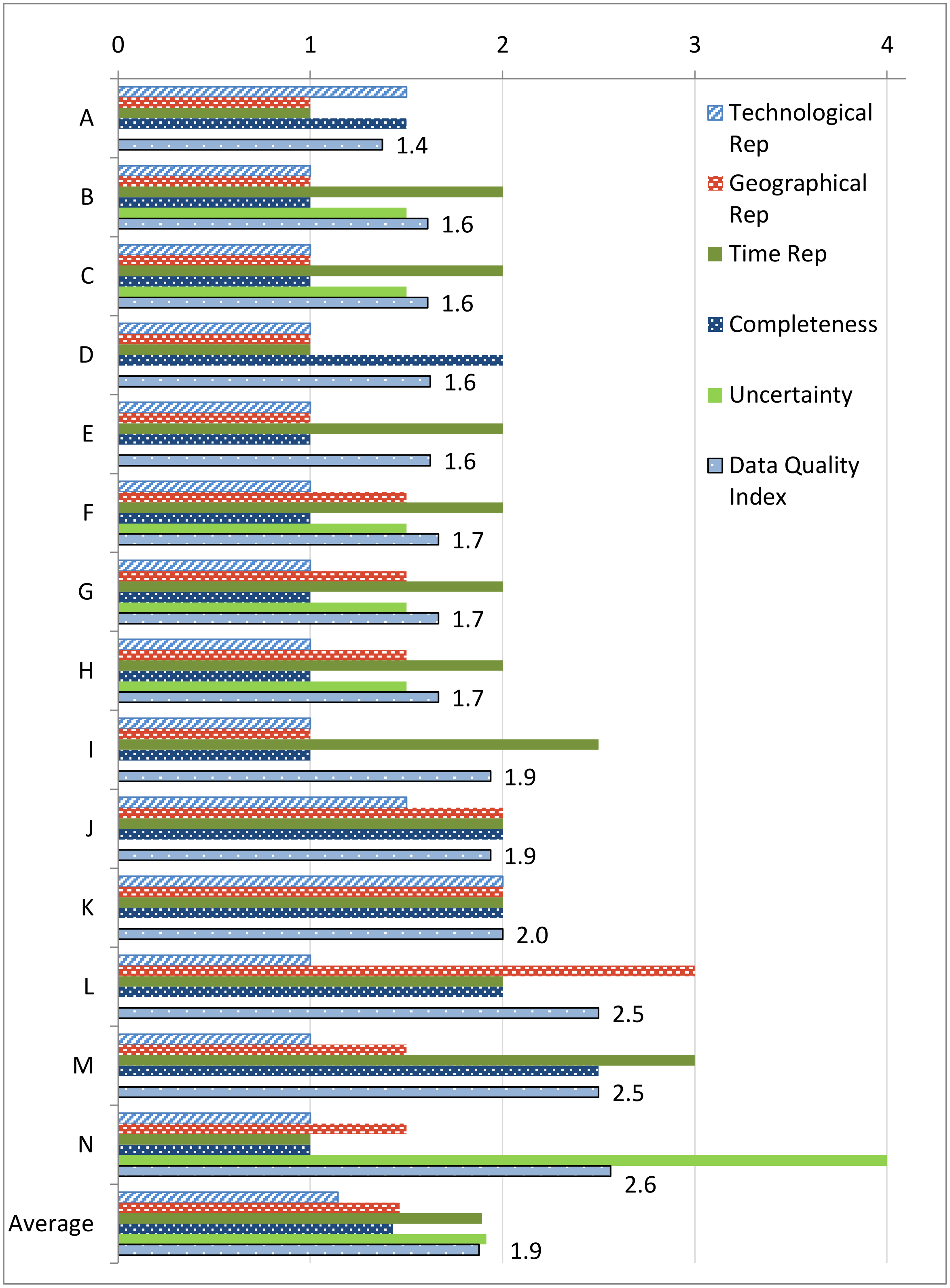


Table 8 – Sugarcane dataset names and identifiers

Sugarcane Dataset Name:	Identifier
Life Cycle Assessment of fuel ethanol from sugarcane in Brazil	O
A comparative Life Cycle Assessment of PE Based on Sugar Cane and Crude Oil	P
an environmental life cycle assessment comparing Australian sugarcane with US corn and UK sugar beet as producers of sugar for Fermentation	Q
Carbon footprint of sugar produced from sugarcane in eastern Thailand	R
Bioproduction from Australian sugarcane: an environmental investigation of product diversification in an agro-industry	S
Sugarcane, at farm/BR (Ecoinvent)	T
Life cycle assessment of Australian sugar cane production with a focus on sugarcane growing	V
A decision support tool for modifications in crop cultivation method based on LCA: a case study on GHG emissions reduction in Taiwanese sugarcane cultivation	V
Life Cycle Assessment of Sugarcane Ethanol and Palm Oil Biodiesel Joint Production	W

Table 9 – Soy dataset names and identifiers

Soy Dataset Name:	Identifier
Soy beans organic, at farm/CH (Ecoinvent)	X
Soy beans IP, at farm/CH (Ecoinvent)	Y
Soybeans; at harvest in (year); at farm; 85-92% moisture (state) (LCA Commons)	Z
Life cycle assessment of soybean based biodiesel production in Argentina	AA
Soybeans, at farm/US (Ecoinvent)	BB
Substitutable biodiesel feedstocks for the UK: a review of sustainability issues with reference to the UK RTFO	CC
Soybean grains, at field (1998-2000)/kg/US (USLCI)	DD
Soybeans, at farm/BR (Ecoinvent)	EE
Soybean grains, at field/kg/US (USLCI)	FF
Biogenic greenhouse gas emissions linked to the life cycles of biodiesel derived from European rapeseed and Brazilian soybeans	GG
Soy bean, from farm (LCA Food DK)	HH

Figure 4 - Sugarcane Data Quality Ratings and Component Scores by Dataset

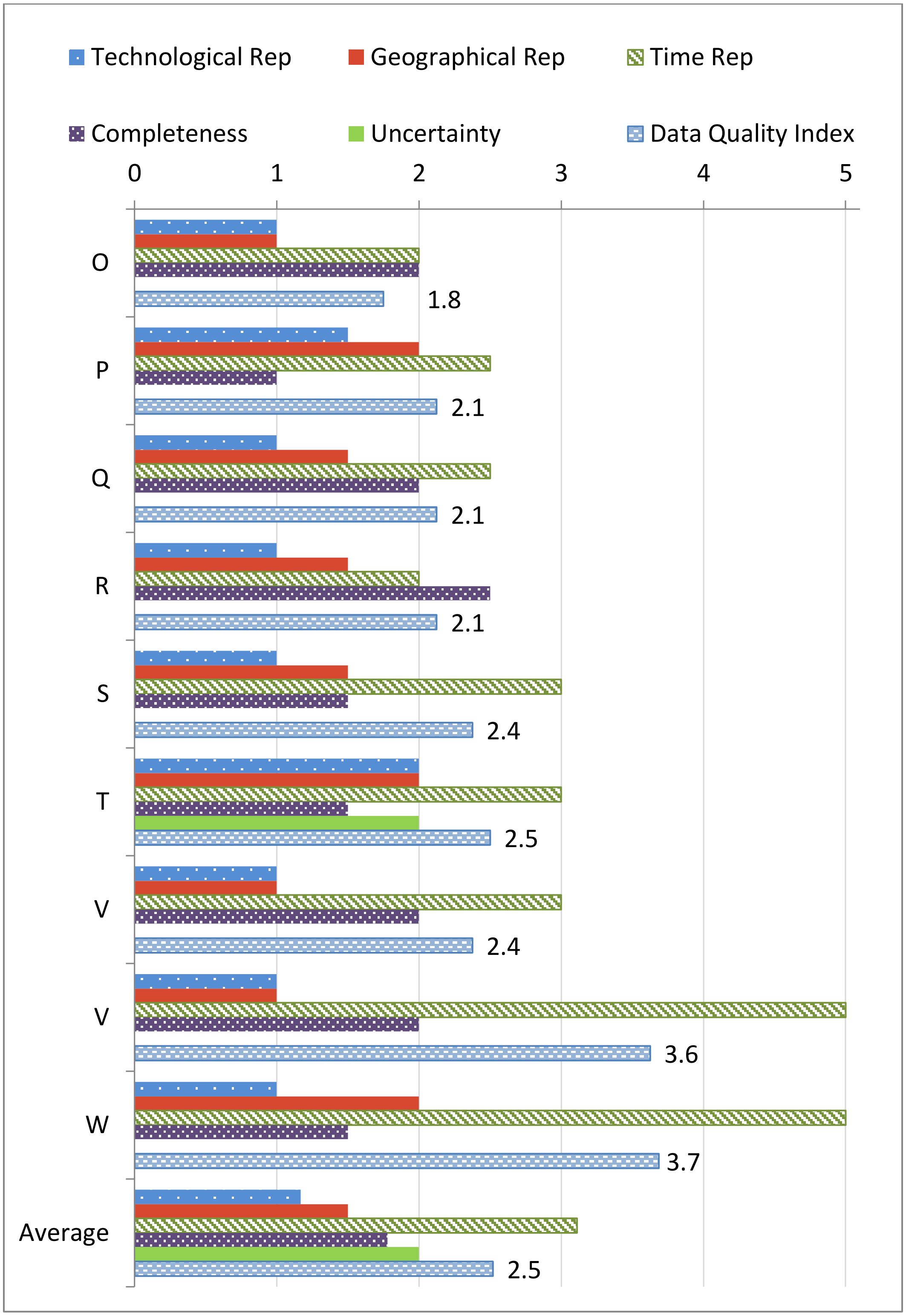
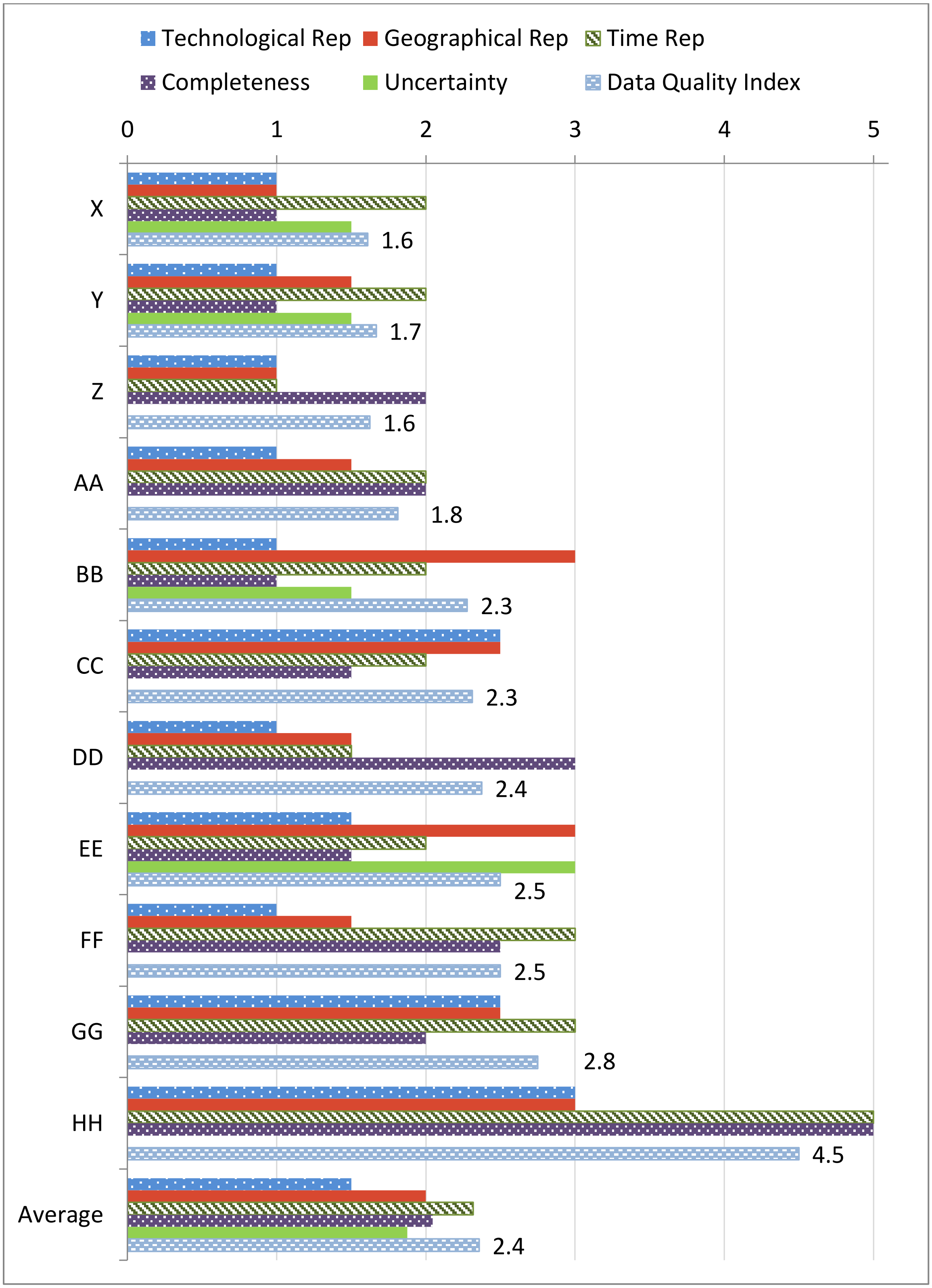


Figure 5 - Soy Data Quality Ratings and Component Scores by Dataset



Overall, the DQRs for the corn datasets ranged from 1.4 to 2.6, with five of the datasets ranked in the high quality range and the remaining eight datasets in the basic quality range. The sugarcane datasets ranged from 1.8 to 3.7, with seven of the datasets in the basic quality range and the remaining two classified as estimates. Sugarcane has no datasets with a DQR in the high quality range. These less desirable DQRs for sugarcane are mainly a result of poorer scores in the category of temporal representativeness. The soy datasets have the largest range of DQRs, from 1.6 to 4.5. Two of the datasets are classified as high quality, with the majority (eight) in the basic quality range. The dataset "Soy bean, from farm", available from the LCA Food DK database, was the lowest scoring of all the datasets assessed with a DQR of 4.5. This rating is outside the range defined by the ILCD handbook for the lowest quality level of estimate (3.0 to 4.0). In the DQR table for soy, it has been given the designation "low quality estimate". The low DQR is a product of receiving the undesirable score of 5 in the categories of both completeness and temporal representativeness. The temporal score was given because the age of the data is unknown, and the completeness score reflects the fact that very few flows are present in the dataset and major omissions were found in both the inputs and the emissions.

Technological Representativeness

The datasets for all three feedstocks consistently scored the best in the technological representativeness category. This means that data from a different process than the one under study rarely had to be used as a substitute to fill a data gap. A technology aspect of corn and soybean cultivation that warrants attention is tilling practices. The method of tilling can have a large effect on the environmental impacts of a system as it affects the use of fossil fuels and soil degradation, among other issues [22]. Conventional till, reduced / conservation till, and no-till are the basic methods used in corn and soy cultivation. In reduced and conservation till, the amount of tilling is decreased in relation to the conventional method, and a different type of plough is usually employed, while no-till uses a different planting technology to eliminate the need to till altogether [22]. A 2010 USDA report estimates that 28.8% of corn in the US was grown using conventional till practices in 2005 compared to 47.5% grown with reduced or conservation tillage, and 23.5% which used no-till technology [23].

Ecoinvent uses a weighted average of conventional and conservation till practices for both corn and soy in their files. Of the 13 datasets evaluated for corn, seven (including Ecoinvent) reflected average tilling practices at the national level. Two represent state level averages, and one was varied by county. One dataset is explicitly for no-till technology. There is no corn dataset specifically representing conservation or reduced tillage practices, despite the fact that this is the most common tillage practice in the US.

A higher percentage of soy was produced using no-till in 2005 than corn (45.3%), while 43.2% used reduced or conservation till technology and the remaining 11.6% was conventional till. Unlike corn, a dataset modeling conservation till is available for soy. However the majority of the soy files (seven of eleven) use a weighted average of conventional and conservation till similar to that used by Ecoinvent.

This weighted average data is not ideal for an LCA study that seeks to model a specific cultivation system because it does not accurately model any one tillage method. Additionally, the state averages vary significantly from the national averages. Texas, for example, produced 68.4% of corn in 2005 using conventional till while Nebraska used conventional till for just 5.7% of its corn production. Therefore, depending on what state is under study, the national average could either over- or under-estimate the amount of inputs and emissions associated with tilling by a wide margin.

Sugarcane has other technological issues worth noting, particularly relating to the method of harvesting. Sometimes sugarcane is burned before harvest, and sometimes it is harvested green. This difference has an effect on emissions to air, and also on the amount of process water used during milling [24]. This is because the burned sugarcane becomes sticky from the release of juices during burning and therefore generally has a large amount of debris mixed in with the harvested cane. As a result, a more vigorous washing process is required during processing. The sugarcane datasets vary in the percentage of cane that is burned before harvest. The Australian datasets reflect the national average of around 40% burned and 60% green at time of harvest, while a Brazilian dataset has the opposite ratio of 60% burned and 40% green harvest [24, 25].

Additionally, there is a significant difference between manual and mechanical harvest. The Ecoinvent file that models sugarcane production in Brazil assumes that 80% of the harvesting is done manually. In contrast, Australia uses dominantly mechanical harvesting, which is reflected in the Australian datasets. Harvesting sugarcane is the part of cultivation that contributes most significantly to global warming [26]. Therefore, data that accurately represents the method used to harvest sugarcane is important for accuracy of the final results of an LCA.

Geographical Representativeness

In the category of geographic representativeness the corn datasets scored fairly well. All but one dataset either represents the area under study or is from a larger area that includes the study area. The exception is a dataset based on a single site field study conducted in central Italy. The publication associated with this data was intended to model corn production in the “Mediterranean region”, so the dataset was classified as from a smaller area within the Mediterranean and therefore was scored at a value of 3 [27].

Four of the corn datasets are based on US average values. This is problematic because the US is quite large, and therefore subject to regional variations not only in weather and conditions, but also in technology. For example, the USDA reports that about 14% of corn grown in 2002 in the US was irrigated [28]. However, this 14% is not evenly scattered over the entire growing region, but concentrated in certain areas. Nebraska, for example, has an irrigation rate of 60.6%, much higher than the national average [29]. A dataset based on national averages would therefore likely underestimate the amount of water used if the system under study was in Nebraska.

More geographically specific data has the potential to solve this problem, and some of it is available. Three datasets model corn cultivation at the county level. Of the three, one is only for water in Minnesota and one is specifically for Scott County, Iowa. These two datasets will therefore be of limited use to practitioners because of their geographic and technological restraints. The third dataset, titled “Annual Report: Life Cycle Assessment to Improve the Sustainability and Competitive Position of Biobased Chemicals: A Local Approach”, by Kim and Dale is far more versatile in scope [9]. It includes detailed data for several counties across corn growing states, and also has the highest DQR (1.4) of all the datasets evaluated. This level of geographic detail is unique to corn cultivation. State level data is the most geographically specific level of information available for all other crops in this report. Only the LCA Commons data is available by state for soy cultivation. The rest of the soy datasets reflect national averages.

This type of regional variation is not unique to the USA. Four of the sugarcane datasets represent Brazilian production, with two specifically for the state of Sao Paulo. Three datasets are for Queensland, Australia. This region accounts for 98% of sugarcane production in Australia, so the lack of data from other areas is not a particularly important gap [24]. However, there is significant variation in the growing conditions and intensity of inputs within this region. One study by Renouf et al. includes datasets for the two areas of Queensland with the most disparate growing conditions [24].

As illustrated by the discussion above, geographical and technological differences are often strongly related, with quality issues bridging both categories. These types of quality issues call into the question the usefulness of datasets based on national averages when there is significant variation within regions.

Temporal Representativeness

Of the three crops evaluated, sugarcane scored the worst in the category of temporal representativeness with five of the nine sets receiving a rating of 3 or above. Two soy datasets have a score of 5 in this category; one is based on primary data of an unknown age, and the other uses a significant amount of data from 1979. Even the Ecoinvent dataset for sugarcane relies on older data than the Ecoinvent files for corn and soy, using data for agronomic inputs from 1988. This is uncharacteristic of the Ecoinvent database, which collected most of their data between the late 1990s and the mid-2000s.

Crop yield data is particularly sensitive to age because of advances in yields over recent years. A yield increase basically has the effect of diluting the environmental impacts of a cropping system by spreading them over more outputs. For this reason, the results of LCA studies involving crops tend to be quite sensitive to yield changes [30]. Therefore, when new data is collected, a high priority should be given to the collection of updated crop yields.

Completeness

Land use change, and specifically indirect land use change, is the largest problem in the category of completeness. Four of the corn datasets do not include any type of land use change data, and only two of the datasets explicitly include indirect land use change. It should be noted that the database files (Ecoinvent, USLCI, and LCA Commons) do not distinguish between the types of LUC at the flow level. Therefore, all that was able to be determined about these files is that they include some land use change data, but it was not possible to distinguish between direct LUC and indirect LUC for these datasets.

This data gap is even more pronounced for sugarcane. Five of the ten datasets evaluated do not account for land use change, and three of those five also do not include land occupation. The Taiwanese sugarcane dataset does not include land use change despite the fact that the article itself states that sugarcane production is expected to expand in the region and that fallow land will likely be converted for cultivation [30]. Additionally, three of the studies that do include LUC also state that their information on this input is not complete. One of the Australian studies that includes land use change presents the data with the qualifier that the methods used to evaluate both LUC and water impacts have significant limitations [31]. Another study echoes this sentiment when it states that the LUC emissions are uncertain due to lack of uniform methods [32]. The Ecoinvent file also follows this pattern as there is a high degree of uncertainty associated with the land use change flows. The soy datasets also deal inconsistently with this impact, although it is less pronounced than in the sugarcane data. Four of the eleven soy files do not include indirect LUC, and two of these also exclude direct land use change.

The significance of this omission varies depending on the system under study. If the study is for an established growing system that is not expanding, than it would not be highly important information to include. However, for most of these crops, production is expanding in response to increased demand for bio-products. This is especially true in South America, where sugarcane production has expanded in Brazil at an average rate of approximately 85,000 hectares per year since 1990 and soy production in Argentina has gone from less than a million hectares to 13 million since 1970 [33, 34].

Uncertainty

As stated in the Methods section, an uncertainty evaluation was only done for the Ecoinvent data. In general, these datasets had low uncertainty since data is mostly based on verified measurements. The exception is that all transport distances in the Ecoinvent datasets are estimates. The Ecoinvent sugarcane datasets also has a greater degree of uncertainty than the soy or corn Ecoinvent datasets because the sugarcane file's energy and carbon dioxide data is partly based on qualified estimates.

Additionally, an uncertainty score was given to one USLCI file: "Corn, production average, US, 2022". It was possible to score this dataset because it is a qualified estimate for corn production in the future, and therefore was given the standard uncertainty score of 4 for qualified estimates.

As discussed above, many studies that included data for LUC expressed concerns of uncertainty along with that data. It was not possible to give an overall uncertainty score to these datasets, however, because these concerns were generally expressed only in qualitative terms and uncertainty information was not available for the other inputs in the datasets.

Processing Data Quality

Figures 6, 7 and 8 illustrate the results of the processing Data Quality Ratings for corn, soy, and sugarcane. Overall, the processing datasets for each crop scored worse than the cultivation datasets. The corn processing datasets have DQRs ranging from 1.6 to 4.1, with only one dataset in the high quality range. The sugarcane datasets range from 1.9 to 3.6, with three datasets in the basic quality range and four that are considered estimates. The soy processing data had the tightest range with datasets scored between 2.3 and 3.1. All but one of the seven soy datasets are in the basic quality range, with a single dataset qualifying as an estimate.

Figure 6 – Corn Processing DQRs and Component Scores by Dataset

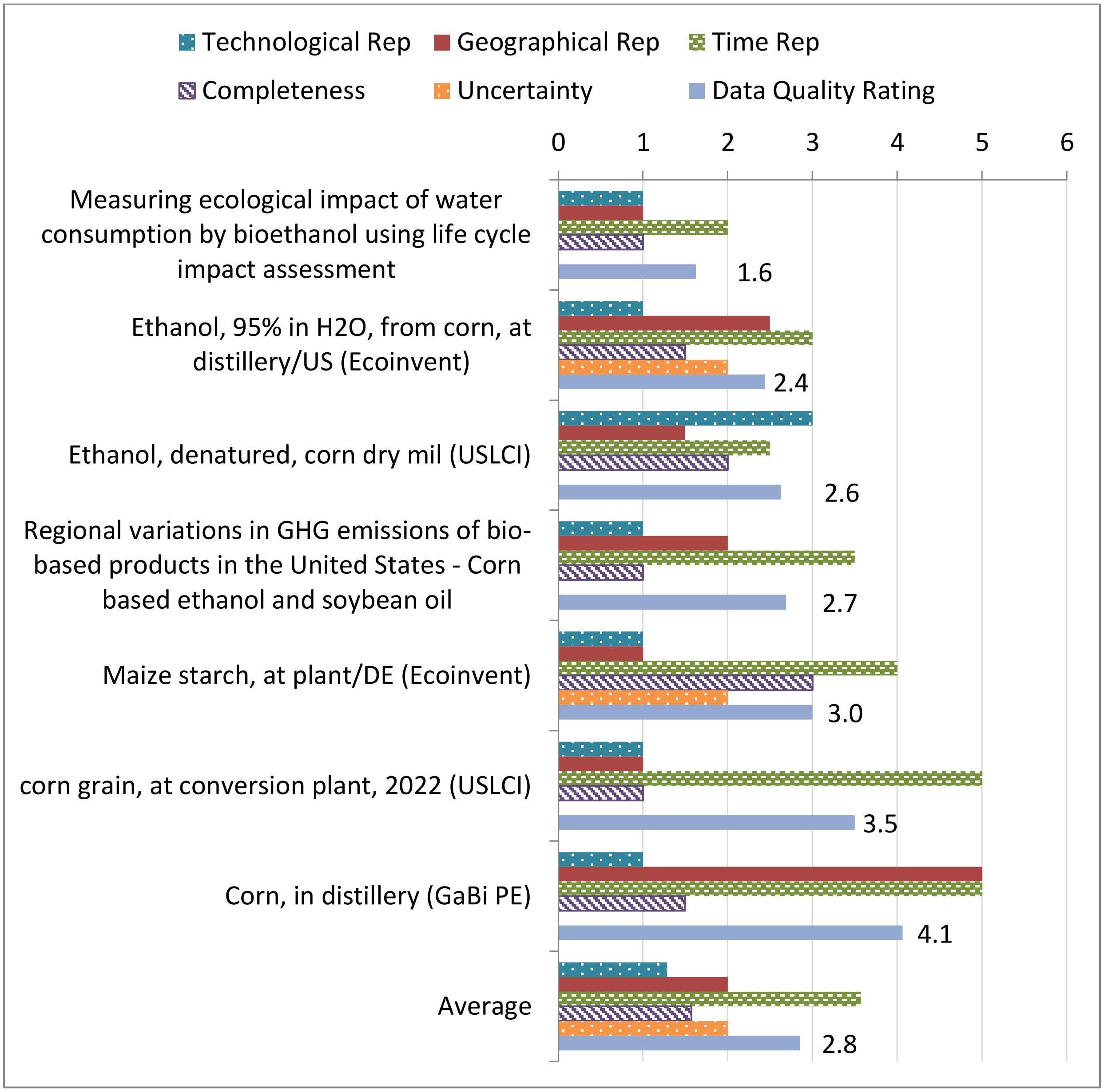


Figure 7- Sugarcane Processing DQRs and Component Scores by Dataset

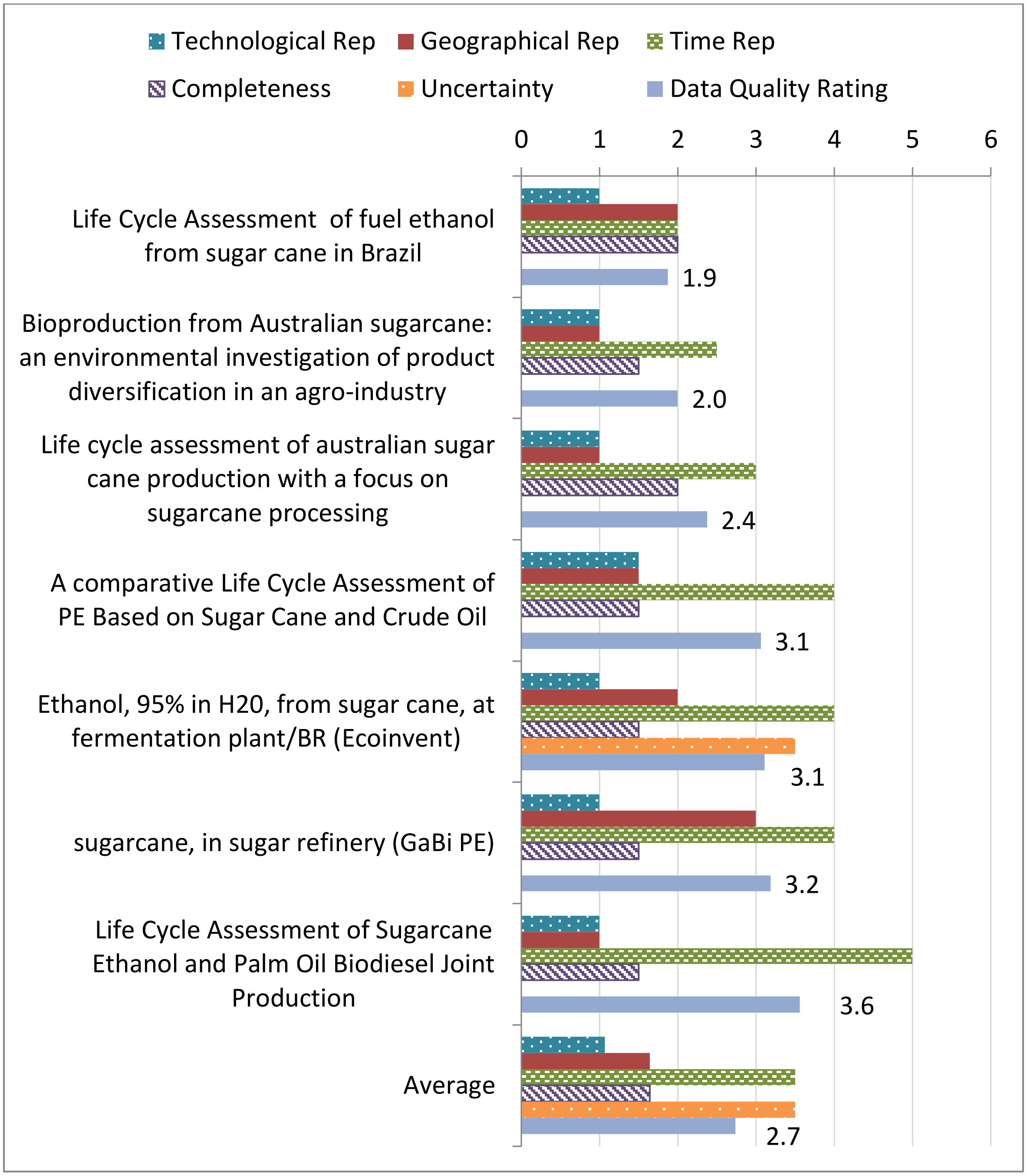
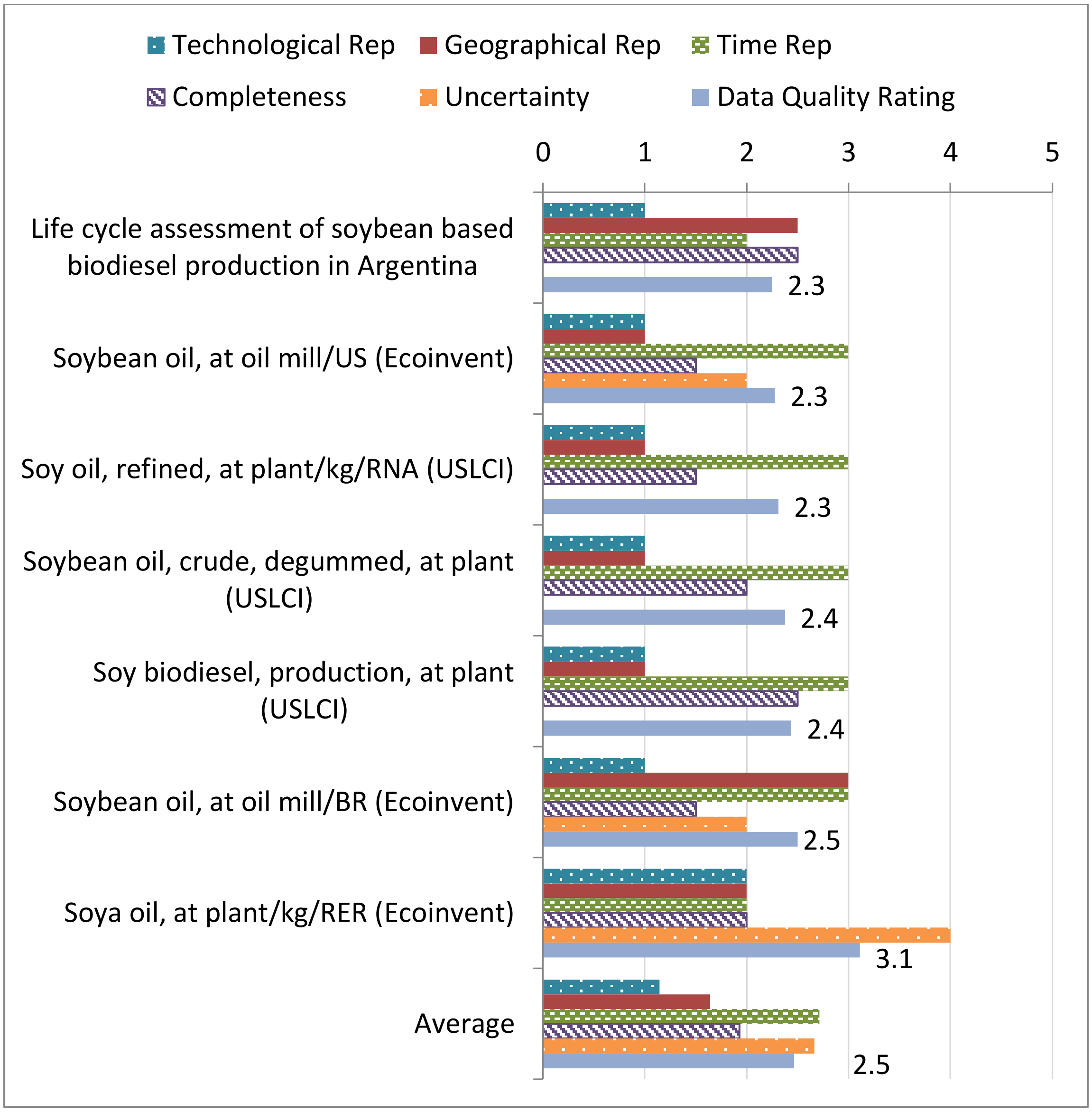


Figure 8 - Soy Processing DQRs and Component Scores by Dataset



The processing data for all three crops scored the worst overall in the category of temporal representativeness. Part of the reason for this is that at least a portion of many of the datasets are from industry statistics and unpublished data. Some of these sources are extremely old and some are of unknown age. One study, "A Comparative Life Cycle Assessment of PE Based on Sugar Cane and Crude Oil", uses data from 1981 but verified that it was still relatively accurate with laboratory experiments.

In general, the documentation of data sources was poorer for the processing datasets than for the cultivation datasets, which is likely because of the use of industry data for which it is often difficult to obtain details. This issue resulted in a diminished ability to accurately assess these datasets. The Ecoinvent datasets also follow this pattern, with high uncertainty relative to the Ecoinvent cultivation files. The combination of these differences results in the processing data having less desirable DQRs as a whole than the cultivation datasets.

5. CONCLUSIONS

Significant data gaps exist in the availability of life cycle inventory data for biobased polymers. These gaps occur geographically, technologically, and temporally. In addition, gaps exist for certain inputs, like land use change, independent of those qualifying factors. National averages are unlikely to adequately represent either technology used to cultivate a crop in any specific region or the growing conditions in that region. There is therefore a need for more regionally explicit data that accurately models the technology and conditions of a specific system under study. Land use change is often not accounted for in otherwise relatively complete datasets, which is a significant quality issue because it can have a large influence on the overall impacts of a system. More data for land use change is needed, and standardized methods for collecting and incorporating such data into LCA studies are also necessary. Newer and better documented processing data is needed for biopolymer feedstocks, and newer data for the cultivation of feedstocks, especially crop yields, would also be beneficial. Finally, the currently available data is skewed heavily to Europe and the USA, leaving a significant portion of the globe with very few datasets available. In conclusion, understanding the impacts caused by the production of bioplastics is the first step on the path to a more sustainable bioplastic, and in order to accurately evaluate these impacts the data gaps described above must be resolved.

APPENDICES

Appendix A: Ecoinvent Uncertainty Scoring Information

Table 10- Ecoinvent Uncertainty Scoring Information

Indicator Score	1	2	3	4	5
Reliability	Verified data based on measurements	Verified data partly based on assumption or non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial expert; data derived from theoretical information	Non-qualified estimate
Completeness	Data from all relevant sites over adequate period to even out normal fluctuations	Data from >50% of relevant sites over adequate period	Data from only some relevant sites (<50%) or >50% of sites but from shorter periods	Representative data from only one relevant site or some sites but for shorter periods	Representativeness unknown or data from a small number of sites and shorter periods
Temporal Correlation	Less than 3 years difference to reference year (2000)	Less than 6 years difference to reference year (2000)	Less than 10 years difference to reference year (2000)	Less than 15 years difference to reference year (2000)	Age of data unknown or greater than 15 years different from reference year (2000)
Geographical Correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from smaller area than are under study, or from similar area		Data from unknown or distinctly different area
Further Technological Correlation	Data from enterprises, processes and materials under study (i.e. identical technology)		Data on related processes or material but same technology, or from processes and materials under study but different technology	Data on related processes or markets but different technology, or data on laboratory scale processes and same technology	Data on related processes or materials but on laboratory scale of different technology
Sample Size	>100	>20	>10	>=3	unknown

Appendix B: Completeness Check

Table 11 - Corn Cultivation Completeness Check

Name	Data Availability	Details	Includes	Data Years	Data Country	Data Source
Corn, at farm/US S - Corn, at farm/US U	Ecoinvent	1 kg corn grain functional unit (water content 14%, carbon content .375 kg/kg fresh mass, biomass energy content 15.9 MJ/kg fresh mass, Yield 9315 kg/ha). Emissions of N2O and NH3 to air are calculated with emission factors from NREL 2006. Emission of nitrate to water is calculated with a nitrogen loss factor of 32%	includes cultivation of corn in the USA including use of diesel, machines, fertilizers, and pesticides	Time of publications	Modeled for USA	modeled with data from literature
Corn, whole plant, at field/kg/US (Corn, at field/kg/US)	USLCI	Harvested acres represent 91% of the planted acres. The impacts of producing 1kg seed are assumed to be equal to producing 1 kg grain. Only consumptive use of water taken into account. This model uses "conservational" or "reduced" tillage.	Seed production, tillage, fertilizer and pesticide application, crop residue management, irrigation and harvesting. Carbon sequestration is credited. Diesel use in industrial equipment included along with electricity and quicklime. Transportation of fertilizers to the farm (400km) by train.	1998-2000	USA	Primary

Table 11 (cont'd)

Grain maize IP, at farm/CH S - Grain maize IP, at farm/CH U	Ecoinvent	1 kg grain maize IP at form with moisture content of 14%. Fresh matter yield/ ha 9279kg. Average production in Swiss lowlands with integrated production. 1996-2003 data collection. This model is non-irrigated.	Includes the processes of soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and shed for machine sheltering is included. Inputs of fertilizers, pesticides and seeds as well as their transports to the regional processing center (10km), and direct emissions on the field. Land occupation (non-irrigated) is included.	1996-2003	Swiss lowlands	Statistics, pilot network, fertilizing recommenda tions, and expert knowledge
Grain maize organic, at farm/CH S - Crain maize organic, at farm/CH U	Ecoinvent	1 kg grain maize IP at form with moisture content of 14%. Fresh matter yield/ ha 9279kg. Average production in Swiss lowlands with integrated production. 1996-2003 data collection	Includes the processes of soil cultivation, sowing, , fertilization, harvest and drying of the grains. Machine infrastructure and shed for machine sheltering is included. Inputs of fertilizers, pesticides and seeds as well as their transports to the regional processing center (10km), and direct emissions on the field. Land occupation (non-irrigated) is included.	1996-2003	Swiss lowlands	Statistics, pilot network, fertilizing recommenda tions, and expert knowledge

Table 11 (cont'd)

Silage maize IP, at farm/CH S - Silage maize IP, at farm/CH U	Ecoinvent	1 kg silage maize IP, at farm. Moisture content 72%	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilizers, pesticides, and seed as well as their transports to the farm are considered. Direct emissions on the field are also included.	1996-2003	Swiss Lowlands	Statistics, pilot network, fertilizing recommendations, and expert knowledge
Corn grain, at harvest in (year), at farm 85-91% moisture (state)	LCA Commons	LCA Commons has very specific datasets for each of the states listed for multiple years. Not all states have data for all years.	fertilizer, water, land use and conversion, transportation, tilling, harvest, pesticide and herbicide use.	1995-2001, 2005	USA: various states	

Table 11 (cont'd)

Silage maize organic, at farm/CH S - Silage maize organic, at farm/CH U	Ecoinvent	1 kg silage maize organic, at farm. Moisture content 72%.	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilizers, pesticides, and seed as well as their transports to the farm (1km) are considered. Direct emissions on the field are also included. Carbon sequestration accounted for.	1996-2003	Swiss Lowlands	Statistics, pilot network, fertilizing recommenda tions, and expert knowledge

Table 11 (cont'd)

Life cycle assessment of various cropping systems utilized for producing biofuels: Bioethanol and Biodiesel	Biomass and Bioenergy 2005	Functional unit 1 Ha arable land used to produce biomass. Corn monoculture with ground cover, corn monoculture with no stover removal and no ground cover, and corn / soybean rotation are modeled. No till agriculture is assumed for all scenarios. Wet milling used to convert corn to ethanol. System expansion method is used to deal with co-products.	agronomic inputs, fuel used in machines, harvesting, wet milling, conversion of stover into ethanol, soybean milling, electricity, fertilizers		USA (Scott County Iowa for corn data)	Soil carbon and nitrogen estimated by DAYCENT model. National Agricultural Statistics Service (agronomic inputs). Climate and soil data from crop site (primary)

Table 11 (cont'd)

LCA of cropping systems with different external input levels for energetic purposes	Journal of Biomass and Bioenergy, July 2012	LCA to evaluate environmental impacts of sunflower and maize, both in rotation with wheat. Reports GWP, eutrophication, and acidification. Three scenarios were studied: Low input, medium input, and high input.	Tilling, fertilizer, weed control, pest control, seed production, transport of inputs to farm, planting, irrigation, harvest. Fuel used in cultivation, machine manufacture and maintenance, direct field emissions,	17-year period, beginning in 1985	Italy	Primary data / field study. Literature data used for machine production and transportatio n of inputs (Bentrup et al 2004, Audsley et al 1997)
Regional variations in GHG emissions of bio-based products in the United States - Corn based ethanol and soybean oil	International Journal of LCA Sept 2009	Corn ethanol represents dry milling process, and Soybean oil was made using the crushing process. GHG only reported category. Data is at the county level, 40 counties in the US corn belt were chosen.	Direct land use change is included. It is measured and the change in soil carbon organic material. Includes impacts associated with the biomass, bio-refining, upstream processes.	2009	USA	Corn cultivation data is from (Kim and Dale 2009)

Table 11 (cont'd)

Life Cycle Assessment to Improve the Sustainabilit y and Competitive Position of Biobased Chemicals: A Local Approach	Unpublished	LCA of soy biodiesel and corn ethanol. System expansion method used to allocate co-product impacts. Both wet and dry milling of corn is modeled. Local bio-refinery data is utilized for each area of study. Data is broken down by county across multiple states.	Fertilizer, fuels, agrochemicals, transport, milling (crushing), electricity, process chemicals	2009 (reported)	USA (Midwest)	Primary / observation and field study.
Measuring ecological impact of water consumptio n by bioethanol using life cycle impact assessment	International Journal of LCA Jan 2012	Ecological impacts of corn based ethanol - water consumption in 81 spacially explicit Minnesota watersheds. Water data taken from Minnesota department of natural resources and water appropriations permit program.	water consumption during corn cultivation and ethanol production	2004-2011 (data sources)	USA (Minnesota)	Minnesota department of natural resources, USDA, Patzek (2006), Mishra and Yeh (2011), Nebraska Energy Office Renewable Fuels Association

Table 11 (cont'd)

Improvements in Life Cycle Energy Efficiency and Greenhouse Gas Emissions of Corn-Ethanol	Journal of Industrial Ecology, February 2009	Researchers created their own Biofuel Energy Systems Simulator (BESS) software to compare different types of corn-ethanol systems in a "seed-to-fuel life cycle. Energy and GHG reported.	Four component submodels for crop production, ethanol biorefinery, cattle feedlot, and anaerobic digestion. Energy for grain drying and irrigation (but not water). energy used for feedstock production and harvesting, including fossil fuels for field operations and electricity for grain drying and irrigation.	2009 (Published)	USA	Crop yields: USDA-NASS, production energy: USDA-ERS (2001). Progressive, high yield cropping scenario: Verma et al (2005).

Table 12 - Sugarcane Cultivation Completeness Check

Name	Data Availability	Details	Includes	Data Years	Data Country	Data Source
Sugarcane, at farm/BR S - Sugarcane, at farm/BR U	Ecoinvent	Cultivation of sugar cane with 20% mechanical harvest and 80% manual harvest	diesel, machines, fertilizers, and pesticides	Time of publications (various)	Brazil	
Life cycle assessment of Australian sugar cane production with a focus on sugarcane growing	International Journal of Life Cycle Assessment Nov 2010	Scenarios modeled for average (all of Queensland) and regional (Wet Tropics and Burkedin) growing. Nitrogen loss from runoff could not be modeled.	Diesel, water for irrigation, seed cane, fertilizer, lime, pesticide, transport of farm inputs, production of "capital goods" i.e. farm equipment.	2002 (agricultural data)-2010 (study published)	Australia	Agriculture inputs: Millford and Pfeffer 2002, industry statistics
A decision support tool for modifications in crop cultivation method based on LCA: a case study on GHG emissions reduction in Taiwanese sugarcane cultivation	International Journal of LCA November 2009	GHG data for the cultivation of Taiwanese sugarcane. System modeled as 1 year new planting, 1 year ratoon, and 1 year fallow.	Soil preparation, growing, harvesting, transport, diesel, direct field emissions, fertilizer, pesticide, herbicide, power generation. Carbon sequestration by sugarcane is taken into account.	1979 (oldest data) - 2009 (published)	Taiwan	Agriculture and Food Agency (2006), Taiwan Sugar Corporation (1979), Water Resources Agency (2003-2005), Interview (2007), Chinese Fertilizer Association (2005)

Table 12 (cont'd)

an environmental life cycle assessment comparing Australian sugarcane with US corn and UK sugar beet as producers of sugar for Fermentation	Biomass and Bioenergy Vol 32 (2008)	Functional unit is 1 kg of glucose or fructose for fermentation. The three things that were found to have the greatest effect on environmental performance were: commodities displaced by co-products, agricultural yields, and nitrogen use efficiency. Each crop was assumed to have the same N, P and K fertilizer profile. This study assumes that all crops were produced in monoculture.	Fertilizer, lime, pesticide, water for irrigation, harvesting, milling, bagasse combustion (for sugarcane only), electricity, transport, machinery, fuel use, clarification.	2008	USA, UK, and Australia	Field Survey: Fuel use in farm equipment, fertilizer and pesticide use, water use, emissions. Industry statistics: Cane yields
Carbon footprint of sugar produced from sugarcane in eastern Thailand	Journal of cleaner production vol 19	Reports estimated GHG emissions from CO_2, CH_4, and N_2O.	Tilling, irrigation, herbicide and pesticide application, diesel, fertilizer, biomass burning, transport, energy use and waste water treatment.	2011	Thailand	Fossil fuel use, sugarcane biomass data, and fertilizer data are from: Field survey, questionnaire and interview.

Table 12 (cont'd)

Life Cycle Assessment of fuel ethanol from sugar cane in Brazil	International Journal of LCA May 2009	Functional Unit is 10,000 Km covered by car of a specific size engine, but data is broken into phases.	Soil preparation, cane plantation, chemical application, harvesting, fuel ethanol process, and energy co-generation	2003-2009	Sao Paulo, Brazil	Water, energy, and emission data from SimaPro (2003) Other: Primary data from sugarcane farms and industries.
Bioproduction from Australian sugarcane: an environmental investigation of product diversification in an agro-industry	Journal of cleaner production Vol 39	System based, consequential approach. A range of scenarios involving different uses for co-products was explored.	Land use change, milling and production, fermentation, additional cane growing (for scenarios 3 and 4).	Published 2012	Australia	Energy flows and balances: Hobson P. (unpublished data). Sugar cane growing: Ranouf et al (2010). Fuel use: APACE (1998), Environment Australia (2002).

Table 12 (cont'd)

A comparative Life Cycle Assessment of PE Based on Sugar Cane and Crude Oil	Journal of Industrial Ecology, June 2012	Details LCA studies of sugarcane-based LDPE produced in Brazil and used/disposed of in Europe, Consequential and attributional LCAs conducted in parallel. Impact categories: GWP, acidification, eutrophication, photochemical ozone creation, primary energy consumption.	Fertilizer production, cane cultivation including LUC, ethanol production, ethylene production, LDPE production. Transport, use phase, and disposal also included. Only CO2 was considered in GWP and only from fossil fuel origin. Biogenic CO2 release was not accounted for, and neither was sequestration during cane growing. Functional unit is 1 kg PE.	2004-2006 (Literature published)	Brazil, Europe	Brazilian data for every step through ethanol production. Sugar cane cultivation data from: Macedo et al (2004), Cheesman (2005), and Smeets et al (2006). Literature sources used to estimate LUC.

Table 12 (cont'd)

Life Cycle Assessment of Sugarcane Ethanol and Palm Oil Biodiesel Joint Production	Journal of Biomass and Bioenergy, September 2012	Three LCA studies were carried out in parallel: one for the traditional sugarcane ethanol system, another for a palm oil biodiesel system, and one for the joint production system of sugarcane ethanol and palm biodiesel.	Seeds, production and use of agricultural inputs, cropping practices, harvesting and transportation, manufacture and maintenance of machineries and agricultural implements, co-products disposal and transportation, manufacture and use of chemicals inputs, manufacture and maintenance of equipment and industrial construction, and co-products energy generation. Land occupation and transformation.		Sao Paulo, Brazil	Primary / field survey and questionnaires

Table 13 - Soy Cultivation Completeness Check

Name	Data Availability	Details	Includes	Data Years	Data Country	Data source
Soybean grains, at field	USLCI	"Carbon Sequestration should be accounted for after the product is built in its LCA model, and should be included depending on the use of end of life fate of that product" (USLCI).	Diesel used on field, electricity and natural gas for farm activities, fertilizer, lime, land occupation, tilling, transport, water for irrigation, pesticide, herbicide	1990-2011	USA	USDA, EPA, Sheehan J (1998), USGS (1999), National Agriculture Statistics, Pesticide Action Network
Soy bean, from farm	LCA Food DK		Land occupation arable, fertilizer, fuel for farm machines, lubricant oil for machines	2002 (Data file created)	Argentina	
Soy beans IP, at farm/CH S - Soy beans IP at farm/CH U	Ecoinvent	1 kg of soy beans IP, at farm with a moisture content of 11%	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and housing. Inputs for fertilizers, pesticides and seed as well as their transports to the regional processing center (10km) are considered, direct emissions on the field also included.	1996-2003	Swiss lowlands	

Table 13 (cont'd)

Soy beans organic, at farm/CH S - Soy beans organic, at farm/CH U	Ecoinvent System Processes / Ecoinvent Unit Processes	1 kg soy beans organic, at farm with moisture content of 11%	Soil cultivation, sowing, fertilization, harvest and grain drying. Machine infrastructure and housing. Inputs for fertilizers, pesticides and seed as well as their transports to the regional processing center (10km) are considered, direct emissions on the field also included.	1996-2004	Swiss lowlands	
Soybean grains, at field/kg/US	USLCI	1 planted acre for 1 year	Seed production, carbon sequestration, tillage, fertilizer and pesticide application, crop residue management, irrigation and harvesting. Only consumptive use of water taken into account. Quicklime and transportation of inputs to the farm is included.	1998-2000	USA	USDA, EPA, Sheehan J (1998), USGS for NOAA (1999), National Agriculture Statistics, Pesticide Action Network
Soybeans, at farm/BR S - Soybeans, at farm/BR U	Ecoinvent	1 kg soybeans modeled with data from literature, some data extrapolated from Europe (production of fertilizers and pesticides), and Switzerland (machine use). Transports modeled for standard distances.	Use of diesel, machines, fertilizers, and pesticides. Carbon sequestration, land transformation and occupation, tilling, sowing, harvesting, seed input, and transport of inputs to the farm.	Time of literature publications (various)	Brazil	

Table 13 (cont'd)

Soybeans; at harvest in (year); at farm; 85-92% moisture (state)	LCA Commons	LCA Commons has specific data for each state listed for various years. Not all states are available for all years.	fertilizer, water, land use and conversion, transportation, tilling, harvest, pesticide and herbicide use, seeding	1996-2000, 2002, 2006	USA: various states	
Substitutable biodiesel feedstocks for the UK: a review of sustainability issues with reference to the UK RTFO	Journal of Cleaner Production 2009	Data for Jatropha, soy, palm oil, rape seed oil, and used cooking oil for production of biodiesel. Reports carbon footprint and GHG savings (except for Jatropha). Includes GHG from direct and indirect land use change.	GHG and carbon footprint only. Land use changes included in this calculation.	2009 (Publish ed)	Import to UK	NGO and Policy sources
Soybeans, at farm/US S - Soybeans, at farm/US U	Ecoinvent	1 kg soybeans with moisture content of 11%. Modeled with data from literature, some data extrapolated from Europe (production of fertilizers and pesticides), and Switzerland (machine use). Transports modeled for standard distances.	Use of diesel, machines, fertilizers, and pesticides. Carbon sequestration, LUC and use, tilling, sowing, harvesting, seed input, and transport of inputs to the farm. Carbon sequestration, land transformation (place holder for ongoing process), land occupation, lime, sowing, tilling, harvesting, and herbicide. Seed inputs also included.	Time of literatur e publicati ons (various)	USA, with some data from Europe and Switzerland	

Table 13 (cont'd)

Life cycle assessment of soybean based biodiesel production in Argentina	International Journal of LCA March 2009	Primary data was obtained for the crop portion of the data only. Economic allocation was used for co-products. Different types of soy (first and second class, conservation till and no till) were used, and weighted by their production volumes. Second class soy uses the residual fertilizers in the soil from the wheat that is cultivated in rotation with it, while first class soy is produced in monoculture and has fertilizers applied.	Only CO2, CH4, and N2O were considered in the global warming calculation. Land use change except for direct de-forestation is excluded. Storage and drying is excluded. Agriculture, extraction and refining, trans-esterification included.	2001-2005	Argentina	Field survey and primary data from Donato et al 2005 used for agriculture data. Ecoinvent data used for all else.
Biogenic greenhouse gas emissions linked to the life cycles of biodiesel derived from European rapeseed and Brazilian soybeans	Journal of Cleaner Production 2009	GHG emissions only. System models soybeans grown for 25 years on land from cleared rainforest or savannah with no tilling.		2009	Brazil, Europe	

Appendix C: Data Quality Ratings

Table 14 - Corn DQR

Name	Data Availability	Data Years	Data Country	Technological Rep	Geographical Rep	Time Rep	Completeness	Uncertainty	Data Quality Rating
Annual Report: Life Cycle Assessment to Improve the Sustainability and Competitive Position of Biobased Chemicals: A Local Approach	Unpublished	2008-2009	USA (Midwest)	Cultivation practices varied by county. State level input statistics used when county level unavailable. Current tillage practices represented.	Data available on a county basis, accounts for variation between locations	Corn data averaged from 2000-2006 (continuous)	System expansion model used, direct land use change included but not indirect.		High
				1.5	1	1	1.5		1.4
Grain maize organic at farm/CH S – Grain maize organic at farm/CH U	Ecoinvent	1996-2003	Switzerland	Represents Organic cultivation in Switzerland	Data is from Switzerland.	Data collected from 1996-2003	High level of completeness.	Low uncertainty Transport distances are estimates.	High
				1	1	2	1	1.5	1.6

Table 14 (cont'd)

Silage maize organic, at farm/CH S - Silage maize organic, at farm/CH U	Ecoinvent	1996-2003	Switzerland	Represents Organic cultivation in Switzerland	Data is from Switzerland.	Data collected from 1996-2003	High level of completeness.	Low uncertainty Transport distances are estimates.	High
				1	1	2	1	1.5	1.6
Corn, at farm/US S – Corn, at farm/US U	Ecoinvent	Time of publications	USA	Data is for the typical cultivation system used in the USA. Tillage practice not stated, but appears to represent conventional tillage practices.	Data for the USA. Regional differences are not accounted for.	Data from 2004-2006. Ecoinvent's reference year is 2000.	High level of completeness.	Most data has low uncertainty. Carbon dioxide and energy from biomass are estimates as well as transport distances.	Basic
				1	1.5	2	1	1.5	1.7
Grain maize IP, at farm /CH S - Grain maize IP, at farm/CH U	Ecoinvent	1996-2003	Switzerland	Represents cultivation system used in Switzerland during the reference period.	Data is from Switzerland with general European data	Data collected from 1996-2003	High level of completeness	Low uncertainty. Transport distances estimates some agronomic inputs have moderate uncertainty.	Basic

Table 14 (cont'd)

				1	1.5	2	1	1.5	1.7
Silage maize IP, at farm /CH S - Silage maize IP, at farm/CH U	Ecoinvent	1996-2003	Switzerland	Represents cultivation system used in Switzerland during the reference period.	Data is from Switzerland with general European data	Data collected from 1996-2003	High level of completeness.	Low uncertainty for most flows. Transport distances are estimates.	Basic
				1	1.5	2	1	1.5	1.7
Corn grain, at harvest in (year), at farm 85-91% moisture (state)	LCA Commons	1995-2001, 2005	USA various states	Data for the system under study (USA) broken down by state.	Data available at state level.	Available as averages of multiple years or as data from individual years.	Relatively complete. Land transformation is accounted for (including the change caused by rotational cropping). However, cutoff values are applied to many inputs.	LCA Commons uses a scoring system of A (good) and B (less good). Uncertainty varies by state and year.	High
				1	1	1	2		1.6

Table 14 (cont'd)

Regional variations in GHG emissions of bio-based products in the United States - Corn based ethanol and soybean oil	International Journal of LCA	2009	USA (by county)	Cultivation practices varied by county are weighted for state level inputs.	Data available on a county basis, accounts for variation between locations	Data from 2000-2008	GHG emission study only. Direct land use change is included. System expansion is used to deal with allocation issues		High
				1	1	2	1		1.6
Measuring ecological impact of water consumption by bioethanol using life cycle impact assessment	International Journal of LCA	2004-2011 (data sources)	USA (Minnesota)	Represents current corn irrigation practices in region under study.	Irrigation requirements for individual farms taken from water permit office, very specific geographic information used.	Data from 2004-2011 with disparate sources. The data from 2004 is USDA corn yield and production data at county level.	Water only, meets study scope		Basic
				1	1	2.5	1		1.9

Table 14 (cont'd)

Life cycle assessment of various cropping systems utilized for producing biofuels: Bioethanol and Biodiesel	Biomass and Bioenergy	2005 (study published)	USA (Scott County Iowa = corn data)	Three scenarios are modeled, all with no-till agriculture. The EPA estimates 2/3 of corn in the US uses conservation tilling, but not necessarily no till	Soil and temperature data is based on one country (Scott country, Iowa). This is within the US, but may not be representative of averages. This is balanced by use of national statistics for agronomic inputs.	Most data is from 2000-2005 with some fertilizer data from 1994 (urea production) and 1998.	System expansion model used, but land use change not included.		Basic
				1.5	2	2	2		1.9
Improvements in Life Cycle Energy Efficiency and Greenhouse Gas Emissions of Corn-Ethanol	Industrial Ecology	2009 (study published)	USA	Standard and "progressive" scenarios modeled. EPA estimates change in the technology used from 2005-2009 (conservation tillage increase from 40% to 70%)	Weighted averages used for input rates. Midwest accounts for 88% of corn production in 2005. The "progressive" model is based on a single field study in Nebraska	Data from 2001-2005, study published in 2009	Does not include direct or indirect land use change		Basic

Table 14 (cont'd)

				2	2	2	2		2.0
LCA of cropping systems with different external input levels for energetic purposes	Biomass and Bioenergy	1985-2002	Italy	Three scenarios (low, traditional, and high input is modeled). S2 represents the standard practice in the area, and conditions are well documented	Primary data from Tuscany, central Italy. The Primary data is from a smaller region than the abstract sites as the area of study (Mediterranean region).	Primary data from field study conducted 1985-2002. Other data from 1997 and 2004. Spread of 19 year the primary data has continuity.	Land use change not accounted for		Basic
				1	3	2	2		2.5
Corn, whole plant, at field/kg/US (Corn, at field/kg/US)	USLCI	Data Sources from 1995-2003	USA	Data is for US cultivation. Averaged conservation and conventional tillage practices. Irrigated system	Data based on US averages, regional variations not captured.	Significant data sources from 1995-2003.	Several dummy processes used to model agrochemicals. Land use change not accounted for.		Basic
				1	1.5	3	2.5		2.5

Table 14 (cont'd)

Corn, production average, US, 2022	USLCI	Estimates 2022	USA	Estimates of production for 2022	Data based on US averages, regional variations not captured.	Calculated estimates for 2022	High level of completeness including land transformation.	From qualified estimates derived from theoretical information.	Basic
				1	1.5	1	1	4	2.6

Table 15 - Sugarcane DQR

Name	Data Availability	Data Years	Data Country	Technological Rep	Geographical Rep	Time Rep	Completeness	Uncertainty	Data Quality Rating
Life Cycle Assessment of fuel ethanol from sugarcane in Brazil	International Journal of LCA May 2009	2003-2009	Brazil	Cane is grown in 6 year cycles. 20% replaced every year. Study reflects the high intensity of inputs typically used in Brazil. Cane is mostly burned before harvest.	Data specific to NE Sao Paulo Brazil	Primary data collected from 2001-2008. N, P, and K fertilizer input data from 2000 and 2003.	Land occupation and land use change are not accounted for. Study uses a cut-off of 0.05% for inputs.		Basic
				1	1	2	2		1.8
A comparative Life Cycle Assessment of PE Based on Sugar Cane and Crude Oil	Journal of Industrial Ecology, June 2012	2004-2006 (Literature published)	Brazil	Both mechanical and manual harvest are modeled. Details of cultivation process modeled are vague.	Brazilian data used for cane cultivation, but from various literature sources. Detailed account of geographic information unavailable.	Data sources range from 2004-2009. Various literature sources used.	Both attributional and consequential methods are used. System expansion is used to deal with coproducts for the consequential method.	Land use change emissions are uncertain due to lack of uniform methods.	Basic

Table 15 (cont'd)

				1.5	2	2.5	1		2.1
an environmental life cycle assessment comparing Australian sugarcane with US corn and UK sugar beet as producers of sugar for Fermentation	Biomass and Bioenergy Vol 32 (2008)	2008	Australia	Monoculture with conventional practices assumed. New planting every 4-6 years. Typical technology for region.	Data for Queensland, which has a large variation in climate conditions. Min and max values are provided for inputs, but variation is represented to a limited extent.	Data for yields (2003) and harvesting energy (2002) are the most significant due to the sensitivity of results to these two items. Other data ranges from 1996-2007.	Land occupation and land use change not accounted for. Some data partly based on estimates. Displacement method used to deal with co-products.	Min and max input values calculated. Variation due to regional differences accounts for most of this. Study does not capture all variation.	Basic
				1	1.5	2.5	2		2.1
Carbon footprint of sugar produced from sugarcane in eastern Thailand	Journal of cleaner production vol 19	2011	Thailand	Sugarcane harvested green and burned. Manual harvest Sugarcane cultivation in Thailand is an established process. Farms in operation for 20 years or longer.	Data is from the study area (Eastern Thailand). Cropping practices were found to vary significantly within this area, which is reflected in the data.	Survey cropping averages from 2003-2007. Soil conditions data is from 1993.	Land occupation and transport of inputs to farm not accounted for. Land use change excluded since this study was conducted on established farms. GHG estimates from CO2, N2O, and CH4.	N fertilizer rate varied by a factor of 18, and the yield varied by a factor of 3.	Basic

Table 15 (cont'd)

				1	1.5	2	2.5		2.1
Bioproduction from Australian sugarcane: an environmental investigation of product diversification in an agro-industry	Journal of cleaner production Vol 39	Published 2012	Australia	Both standard cropping system and "eco-efficient" cropping system modeled. Input levels for both clearly defined.	Data used from Queensland (98% Australian production), but does not capture variation in the region as averages are used.	Data from Renouf et al 2010 is rated at 3. Other data introduced in this study is consistent with this timeframe (2004-2009).	Based on data from Renouf et al 2010, but includes land use change and a progressive cropping scenario. However, the methods used to evaluate water and land use have significant limitations.		Basic
				1	1.5	3	1.5		2.4

Table 15 (cont'd)

Sugarcane, at farm/BR S Sugarcane, at farm/BR U	Ecoinvent	Time of literature publications (various)	Brazil	Harvesting is assumed to be 20% mechanical and 80% manual. Not indicated if cane is harvested green or burned. Tillage practice not identified.	Data modeled from literature. Most data specific to Brazil, but US electricity used.	Data for land use and change from 1996. Data for some agronomic inputs from 1988, and harvesting and fram activities data is from 1996. All other data within 3 years of reference year.	Most flows are complete. Land occupation and transformation as well as energy from biomass and CO2 have uncertain completeness.	Most inputs have very low uncertainty, but CO2 and energy from biomass are qualified estimates (score of 4 on pedigree matrix)	Basic
				2	2	3	1.5	2	2.5
Life cycle assessment of Australian sugar cane production with a focus on sugarcane growing	International Journal of Life Cycle Assessment Nov 2010	2002 (agricultural data)-2010 (study published)	Australia	60% irrigated, 39% burned before harvest. Methods modeled are varied by region, based on field survey. 5-6 year cropping cycles modeled, some with fallow periods	Average scenario modeled for Queensland (98% Australian production), scenarios also modeled for areas within Queensland to capture variability.	Eight year gap between agricultural data and study publication.	N loss from runoff not accounted for. Scope of the study does not include land use change.	Monte Carlo analysis revealed "significant variation"	Basic

Table 15 (cont'd)

				1	1	3	2		2.4
A decision support tool for modifications in crop cultivation method based on LCA: a case study on GHG emissions reduction in Taiwanese sugarcane cultivation	International Journal of LCA November 2009	1979 (oldest data) - 2009 (published)	Taiwan	3 year cropping cycle assumed (planting-ratoon-fallow). Varying levels of inputs modeled to compare effect on yield and GHG emissions.	Most data specific to Taiwan. Some Chinese data used for fertilizer production impacts.	A significant amount of data is used from 1979 from the Taiwanese Sugar Corporation. Including agricultural inputs and machinery.	Land use change is not included despite the fact that sugarcane production is expected to increase in Taiwan and fallow land will likely be converted.	Sensitive to sugarcane yield	Data Estimate
				1	1	5	2		3.6

Table 15 (cont'd)

Life Cycle Assessment of Sugarcane Ethanol and Palm Oil Biodiesel Joint Production	Journal of Biomass and Bioenergy, September 2012		Brazil	Based on regional data that reflects actual practices in that region.	Sugarcane data from Sao Paulo, Brazil. Palm data from a different region. This may affect the accuracy of the predictions in the "joint production" model. Only 3 refineries surveyed. Effects of using different types of land are discussed.	Data sources from 1995-2008, study published 2012. Main data sources are primary data / surveys. No information about the dates of the surveys is available.	All major components are accounted for. However, detailed info about the agricultural inputs used is not available and the transport of inputs to the farm is not accounted for.		Data Estimate
				1	2	5	1.5		3.7

Table 16 - Soy DQR

Name	Data Availability	Data Years	Data Country	Technological Rep	Geographical Rep	Time Rep	Completeness	Uncertainty	Data Quality Index
Soy beans organic, at farm/CH S - Soy beans organic, at farm/CH U	Ecoinvent	1996-2003	Switzerland	Represents organic cultivation in Switzerland during the data years	Data from Switzerland.	Data from1996-2003	High level of completeness.	Low level of uncertainty for most flows. Transport distances are estimates.	High
				1	1	2	1	1.5	1.6
Soy beans IP, at farm/CH S - Soy beans IP at farm/CH U	Ecoinvent	1996-2003	Switzerland	Represents cultivation method typical in region during data period.	Data from Switzerland and Europe	Data from 1996-2003	High level of completeness.	Low level of uncertainty for most flows. Transport distances are estimates.	Basic
				1	1.5	2	1	1.5	1.7

Table 16 (cont'd)

Soybeans; at harvest in (year); at farm; 85-92% moisture (state)	LCA Commons		USA	Represents system under study. Variation is accounted for.	Data for the USA broken down by state. Variation captured.	Data available as average over several years or for individual years.	Relatively complete. Land transformation is accounted for (including the change caused by rotational cropping). However, cutoff values are applied to many inputs.	LCA Commons uses a scoring system of A (good) and B (less good). Uncertainty varies by state and year.	High
				1	1	1	2		1.6
Life cycle assessment of soybean based biodiesel production in Argentina	International Journal of LCA March 2009	Published 2009	Argentina	Represents cultivation practices typical of the region weighted by production volume.	Differences between regions are weighted based on productions volume, but further refinement is called for.	Majority of data is from 2005 through 2007. Some background data from early 2000s used.	Most major contributors accounted for, but only direct deforestation is measured for land use change.		Basic

Table 16 (cont'd)

				1	1.5	2	2		1.8
Soybeans, at farm/US S - Soybeans, at farm/US U	Ecoinvent	Literature sources 2004-2006	USA	Represents system under study.	Some data from the US, but many inputs adapted from Swiss and European data.	Literature sources published 2004-2006	High level of completeness	Co2 and energy from biomass are calculated estimates. Transport distances also estimates.	Basic
				1	3	2	1	1.5	2.3
Substitutable biodiesel feedstocks for the UK: a review of sustainability issues with reference to the UK RTFO	Journal of Cleaner Production 2009	Published 2009	Soy data is for South America	Details of the agricultural system modeled are vague, but monoculture with high amount of agro chemicals is assumed. Data from multiple sources used.	Data from various regions in South America used (Brazil, Argentina, and Bolivia) but variation between regions not distinguished. Unclear what types of data were used from each region.	Soy data from 2003-2009. Multiple sources used.	GHG only, matches study scope. Direct Land use change is accounted for based on different conversion scenarios. Indirect land use change not accounted for.		Basic
				2.5	2.5	2	1.5		2.3

Table 16 (cont'd)

Soybean grains, at field (1998-2000)/kg/US	USLCI	1998-2000	USA	Based on US averages. Weighted conventional and conservation tillage.	Based on US averages, regional differences not accounted for.	Significant data sources from 1995-2003.	Several dummy flows used to model agrochemicals. Farm processes (harvesting, tilling etc) not called out in flows.		Basic
				1	1.5	1.5	3		2.4
Soybeans, at farm/BR S - Soybeans, at farm/BR U	Ecoinvent	Modeled from literature	Brazil	Represents cultivation system under study, but unclear if conventional or conservation tillage is used.	Some data specific to Brazil, but agronomic inputs adapted from Swiss and European data.	Literature sources published 2001-2006	High level of completeness including land transformation from forest and shrub land. However, application of Lime is not accounted for.	CO2 and energy from biomass are calculated estimates. Transport distances also estimates. Significant uncertainty in agronomic inputs.	Basic
				1.5	3	2	1.5	3	2.5

Table 16 (cont'd)

Soybean grains, at field/kg/US	USLCI	1997-2010	USA	Based on US averages. Weighted conventional and conservation tillage.	Based on US averages, regional differences not accounted for.	1997-2010 from various sources.	Dummy processes are used for several chemicals and land use change is not accounted for.		Basic
				1	1.5	3	2.5		2.5
Biogenic greenhouse gas emissions linked to the life cycles of biodiesel derived from European rapeseed and Brazilian soybeans	Journal of Cleaner Production 2009	Submitted 2007	Brazil	Different scenarios (no till and conventional till) modeled. Data mostly based on averages. Economic allocation used but based on prices from Europe.	Some data from Europe and the US adapted for Brazil. Regional variations not accounted for.	Data from 1998 - 2008 from disparate sources.	Carbon and GHG only, matches scope of study. However, many estimates used. Study assumes land will be abandoned after 10 or 25 years.		Basic
				2.5	2.5	3	2		2.8

Table 16 (cont'd)

Soy bean, from farm	LCA Food DK	Unknown	Argentina	Cultivation of soy but unspecified technology	Arable land data is from Argentina, other data generic.	Unknown	Very few flows present. Types of fertilizer unspecified. Emissions incomplete.		Low Quality Estimate
				3	3	5	5		4.5

Appendix D: Processing Data Completeness Check

Table 17 - Corn Processing Completeness Check

Name	Data Availability	Details	Includes	Data Years	Data Country	Data Source
corn grain, at conversion plant, 2022	USLCI	This process transports corn grain to the conversion plant. It does so using transportation modal allocation from the USDA Ethanol Backgrounder (2007), assuming this current allocation will apply in 2022. Distances for each mode are from a combination of references; still missing a good distance estimate for barge, but since the share of barge transportation is ~2%, the final result will not be sensitive to this parameter.	Infrastructure impacts are included in this process by calling the Ecoinvent "transport" processes. The production of corn grain feedstock utilized in this transport process allocates inputs to the stover and grain based on the amount of ethanol that can be produced from each co-product.	2022	USA	Unknown

Table 17 (cont'd)

Maize starch, at plant/DE S - Maize starch, at plant/DE U	Ecoinvent System Processes / Ecoinvent Unit Processes	This process is the production steps required to obtain maize starch from corn. The corn input refers to Grain Maize IP. Allocation was done on an economic basis. Moisture content is 14% by weight. The only emission included in this process is heat. No other emissions to the environment are accounted for.	Mechanical separating steps, swelling in process water, milling of the swelled corns, desiccation and drying of the extracted starch. Processing of water was included as well as infrastructure use.	1998	Germany	Detailed literature study
Ethanol, denatured, corn dry mil	USLCI	processing data for corn grain, at conversion plant 2022	Corn dried and stored, milling, gluten drying, waste disposal, fermentation, electricity, and process water. Infrastructure not included.	2000-2010	North America	McAloon 2000, Hsu 2010, Mueller 2007

Table 17 (cont'd)

Corn, in distillery	GaBi PE	Production of 1 kg hydrated ethanol 95% dry basis (1.05kg wet basis). Also delivers co-product "DDGS, from corn, at distillery". Economic allocation w/ factor of 97.6% to ethanol. Allocation according to carbon balance for CO2 emissions. Does not specify which Ecoinvent file data is taken from.	Infrastructure, transport to facility, waste treatment, process chemicals, process energy, water.	Unknown	USA	Ecoinvent, modified by GaBi
Ethanol, 95% in H2O, from corn, at distillery/US S - Ethanol, 95% in H2O, from corn, at distillery/US U	Ecoinvent Unit Process	1 kg hydrated ethanol 95% (dry basis, i.e. 1.05 kg hydrated ethanol wet basis). Dry milling technology. Economic allocation 97.6% to ethanol. CO2 emissions are allocated based on carbon balance.	transport of corn grains to the distillery, processing to hydrated ethanol. System boundary is at the distillery and dehydration is not included.	1990-2006	USA	Project Alcosuisse, industrial data, literature. Tramsport distances estimates.

Table 17 (cont'd)

Regional variations in GHG emissions of bio-based products in the United States - Corn based ethanol and soybean oil	International Journal of LCA Sept 2009	Corn ethanol represents dry milling process, and Soybean oil was made using the crushing process. GHG only reported category. Data is at the county level, 40 counties in the US corn belt were chosen. System expansion is used to deal with allocation. DDGS displaces corn, soy meal, and nitrogen in urea.	Dry milling process: grinding, cooking, fermentation, distillation and DDGS recovery. Chemicals used are caustic lime, soda, sulfuric acid, and urea.	1991-2009	USA	Literature and industry sources from 1991-2009. Background data from Ecoinvent and Ecobilan.

Table 17 (cont'd)

Measuring ecological impact of water consumption by bioethanol using life cycle impact assessment	International Journal of LCA Jan 2012	Ecological impacts of corn based ethanol - water consumption in 81 spatially explicit Minnesota watersheds. Water data taken from Minnesota department of natural resources and water appropriations permit program.	Water consumption during corn cultivation and ethanol production. Represents dry milling process.	2006-2011 (data sources)	USA (Minnesota)	Minnesota department of natural resources water permit appropriation program, USDA (2004, 2010), Patzek (2006), Mishra and Yeh (2011), Nebraska Energy Office (2011), Renewable Fuels Association (2008).

Table 18 - Sugarcane Processing Completeness Check

Name	Data Availability	Details	Includes	Data Years	Data Country	Data Source
sugarcane, in sugar refinery	Gabi-PE	The multi-output process "sugarcane, in sugar refinery" delivers the co-products: Sugar, ethanol 95% in H2O, sugarcane molasses, bagasse, electricity, and vinasse. Economic allocation with 80-85% to sugar and 10-11% to ethanol. Allocation according to carbon balance for CO2. Sugar Cane used is from "sugar cane , at farm" BR	Process energy (from burning of residues, coal, and wood), process water (tap), waste disposal (modeled with CH municipal disposal, ash disposal both landfill and incineration), ethanol fermentation plant, limestone, transport (unspecified), wastewater treatment, process chemicals, and sugar refining. Land use / transformation not included.	2011 (entered into database)	Brazil	

Table 18 (cont'd)

Ethanol, 95% in H20, from sugar cane, at fermentation plant/BR S - Ethanol, 95% in H20, from sugar cane, at fermentation plant/BR U	Ecoinvent	Allocation based on economic criteria.	Fermentation of sugar cane including materials, energy uses, infrastructure, and emissions. Lubricating oil for machines included.	Time of publications	Brazil	Publications. Also "some data are derived from other or unknown plant or have been estimated".
Life Cycle Assessment of fuel ethanol from sugar cane in Brazil	International Journal of LCA May 2009	Functional Unit is 10,000 Km covered by car of a specific size engine, but data is broken into phases. Waste water from the ethanol process is used to irrigate the fields, transported there by trucks.	Cane Washing, juice extraction, refining, fermentation, and distillation of ethanol. Electricity co-generation by steam.	2003-2008	Sao Paulo, Brazil	Water, energy, and emission data from SimaPro (2003) Other: Primary data from sugarcane farms and industries (2001-2008)

Table 18 (cont'd)

Bioproduction from Australian sugarcane: an environmental investigation of product diversification in an agro-industry	Journal of cleaner production Vol 39	System based consequential approach. A base case and 5 scenarios are represented. In the base case, the mill produces sugar and molasses (used as animal feed). Scenario 1: excess electricity from bagasse is exported to the grid. Scenario 2: ethanol is made from molasses. Scenario 3: ethanol is made from bagasse. Scenario 4: ethanol is made from cane juice with increased sugarcane production. Scenario 5: PLA is made from cane juice with increased sugarcane production.	Cane crushing, juice extraction and purification, concentration and crystallization (if applicable). Fermentation including chemical inputs, and PLA production included.	Published 2012	Australia	Energy flows and balances: Hobson P. (unpublished data). Sugar cane growing: Ranouf et al (2010). Fuel use: APACE (1998), Environment Australia (2002). Background Data: Life Cycle Strategies (2009). Fermentation: Aden et al (2002). PLA production: Vink et al (2003).

Table 18 (cont'd)

A comparative Life Cycle Assessment of PE Based on Sugar Cane and Crude Oil	Journal of Industrial Ecology, June 2012	Details LCA studies of sugarcane-based LDPE produced in Brazil and used/disposed of in Europe, and fossil-based LDPE produced, used, and disposed of in Europe. Consequential and attributional LCAs conducted in parallel. No major differences found between the two methods for "key" impacts. Impact categories: GWP, acidification, eutrophication, photochemical ozone creation, primary energy consumption. Only CO2 was considered in GWP and only from fossil fuel origin. Biogenic CO2 release was not accounted for, and neither was sequestration during cane growing. Functional unit is 1 kg PE.	Cultivation of cane, cane washing, crushing, juice extraction, PH adjustment, fermentation and distillation included in ethanol production. Ethylene production: heating, dehydration by aluminum catalyst, and purification to PE grade ethylene. LDPE production: polymerization at 130-330 C and 81-276 mpa.	1981- 2009 (Literature published)	Brazil, Europe	Brazilian data for every step through ethanol production. Ethanol yield data from: Macedo et al (2004). PE production based on process simulation and literature (Kochet et al. 1981 and Barrocas and Lacerda 2007). Data from NTM 2009, Bargigli et al. 2004, cottro et al 2003, and Tillman et al. 1992 also used.

Table 18 (cont'd)

Life Cycle Assessment of Sugarcane Ethanol and Palm Oil Biodiesel Joint Production	Journal of Biomass and Bioenergy, September 2012	Three LCA studies were carried out in parallel: one for the traditional sugarcane ethanol system, another for a palm oil biodiesel system, and one for the joint production system of sugarcane ethanol and palm biodiesel. GHG and Energy only.	Manufacture and use of chemicals inputs, manufacture and maintenance of equipments and industrial construction, and co-products energy generation.	2012 (published)	Sao Paulo, Brazil	Primary / field survey and questionaires. Data for ethanol production collected from three biorefineries.

Table 18 (cont'd)

Life cycle assessment of Australian sugar cane production with a focus on sugarcane processing	International Journal of Life Cycles Assessment 2011	Three scenarios are modeled. 1) sugar mill produces only sugar an molasses. Power is generated from bagasse combustion with no co-generation. 2) sugar mill produces sugar and molasses with co-generation from bagasse. Excess power is exported to the grid. 3) Sugar mill uses co-generation and produces ethanol from molasses. Economic, mass, and system expansion methods of allocation are all modeled. Water evaporated from cane juice is used for processing.	process energy from bagasse, dunder (used on fields), process chemicals, flocculent, lubricant for machinery, displaced products for system expansion; sorghum, electricity, LP steam, potassium chloride. Cane crushing, juice purification, juice concentration, crystallization, and fermentation. Fossil fuels for start-up of boilers are not included.	Study published 2011. Data sources 2007, 2009.	Australia	"Industry consultation" in association with Sugar Research and Innovation at Queensland University of Technology (unpublished data). Australian LCI database (2007), and Ecoinvent (2009).

Table 19 - Soy Processing Completeness Check

Name	Data Availability	Details	Includes	Data Years	Data Country	Data source
Soya oil, at plant/kg/RER S Soya oil, at plant/kg/RER U	Ecoinvent	Soy data file refers to "Soy bean IP, at farm/CH". This process refers to their further processing. Process energy is provided by natural gas. Processing is done in Europe with beans that are assumed to be imported.	Transport to process facility, process energy (electricity and natural gas), organic chemicals for processing. Conditioning of the beans, but not drying, is included. Infrastructure and land use.		Europe	Reusser 1994, Cederberg 1998, von Daniken et al. 1995. Some values provided by European manufacturing companies.
Soybean oil, at oil mill/BRS – Soybean oil, at oil mill/BR U	Ecoinvent	Soy data refers to "Soybeans, at farm/BR U"	Transport to mill, processing into oil and meal. Process chemicals are accounted for as well as process energy.	1998-2005	Brazil (adapted from US data)	Data from a US study, cross checked with literature sources, industrial data. Energy data from national statistics.

Table 19 (cont'd)

Soy oil, refined, at plant/kg/RNA	USLCI	Further processing of "Dummy Soybean oil, crude, degummed, at plant/kg/RNA". No impacts are associated with this dummy file. Energy data is from the late 2000s and all other data is theoretical. Carbon sequestration should be accounted for by the practitioner based on the oil use.	Soy input refers to "Soy, degummed, at plant". This process adds process water, process energy (natural gas and electricity), and transport to processing facility. It also includes sodium hydroxide (process chemical) and disposal of liquid wastes.	Late 2000s	USA	
Soybean oil, crude, degummed, at plant	USLCI	Processing of Soy into Soy oil. "Refers to Soybean grains, at field"	Energy, process chemicals, water, transportation to processing facility, and dummy process for waste disposal.	2010	USA	Omni Tech 2010, NOPA
Soybean oil, at oil mill/US S - Soybean oil, at oil mill/US U	Ecoinvent	Soy data file refers to "soybeans, at farm/US" Allocation based on carbon balance. Solvent extraction modeled, typical for USA.	Includes carbon sequestration, soybean inputs, transport to the oil mill, infrastructure of the oil mill, process water (tap), process energy, and process chemicals.	2006 (data file created)	USA	US study and literature sources, energy data from national statistics

Table 19 (cont'd)

Soy biodiesel, production, at plant	USLCI	"CARBON SEQUESTRATION should be accounted for after the product is built in its LCA model, and should be included depending on the use of end of life fate of that product"(USLCI).	Materials, process energy, water, transport,		North America	
Life cycle assessment of soybean based biodiesel production in Argentina	International Journal of LCA March 2009	Primary data was obtained for the crop portion of the data only. Economic allocation was used for co-products. Oil extraction and trans-esterification data adapted from Jungluth et al 2007 and IDIED 2004. Solvent extraction is modeled. Allocation factors, yields, natural gas, electricity consumption and mix, and transport distances are specific to Argentina.	Only CO2, CH4, and N2O were considered in the global warming calculation. Land use change except for direct de-forestation is excluded. Storage and drying is excluded. Agriculture, extraction and refining, trans-esterification included.	2001-2005	Argentina	Jungluuth et al 2007, IDIED 2004.

Appendix E: Processing Data Quality Ratings

Table 20 - Corn Processing DQR

Name	Data Availability	Data Years	Data Country	Technological Rep	Geographical Rep	Time Rep	Completeness	Uncertainty	Data Quality Rating
Maize starch, at plant/DE S - Maize starch, at plant/DE U	Ecoinvent	1998 (volume) 2007 (data file created)	Germany	Represents technology under study	Refers to typical conditions in Germany	Most data of unknown age. Production volume taken from 1998.	Water, power, transport and infrastructure accounted for. The only emission is heat. No process chemicals accounted for.	Low uncertainty for most flows. Transport distances are estimates.	Estimate
				1	1	4	3	2	3.0

Table 20 (cont'd)

Ethanol, 95% in H2O, from corn, at distillery/US S - Ethanol, 95% in H2O, from corn, at distillery/US U	Ecoinvent	Data from 1990 -2006	USA	Represents technology under study	Data for USA adapted mainly from Europe (similar conditions). US electricity used.	Data from 1990-2006, data file created in 2006. However, data reflects current processing technology.	Facility land use and transformation not accounted for. Otherwise complete.	Low uncertainty for most flows. Transport distances are estimates.	Basic
				1	2.5	3	1.5	2	2.4
Ethanol, denatured , corn dry mil	USLCI	Data from 2000-2010	North America	File claim corn dry milling, but input flows refer to wet milling inputs.	Data for North America, bur no regional variations accounted for.	Data from 2000-2010 from literature sources. Data file was established in 2011. Energy input data is from 2007.	Good level of completeness but infrastructure and land use not accounted for.		Basic
				3	1.5	2.5	2		2.6

Table 20 (cont'd)

corn grain, at conversion plant, 2022	USLCI	2005	North America	Data is for technology under study	Data for area under study	Data is from 2005, this file is an estimate for 2022	Transport only, meets study scope	Barge transport distance is uncertain, but this is less than 2% of the total transport distance.	Estimate
				1	1	5	1		3.5
Regional variations in GHG emissions of bio-based products in the United States – Corn based ethanol and soybean oil	International Journal of LCA Sept 2009	1991-2009	USA	Data is for technology under study	Site specific data not available, industry averages used.	Oldest foreground data from 1998 and oldest background data from 1991. Chemical data from 2000. Industry process statistics from a range of 10 years.	GHG only, meet study scope. Inputs have good completeness.		Basic
				1	2	3.5	1		2.7

Table 20 (cont'd)

Measuring ecological impact of water consumption by bioethanol using life cycle impact assessment	International Journal of LCA Jan 2012	2006-2011	USA (Minnesota)	Data is for technology under study	Facility specific data from Minnesota DNR water permits.	Data is from 2006-2011. Study published in 2012	Water only, matches study scope.			High
				1	1	2	1			1.6

Table 21 - Sugarcane Processing DQR

Name	Data Availability	Data Years	Data Country	Technological Rep	Geographical Rep	Time Rep	Completeness	Uncertainty	Data Quality Rating
Life cycle assessment of Australian sugar cane production with a focus on sugarcane processing	International Journal of Life Cycles Assessment 2011	2011 (published)	Australia	Three scenarios, representative of the area, are modeled.	Data is for Queensland, Australia. This accounts for 98% of Australian production.	Unpublished data is of unknown date. Most other data from 2004-2009, but oldest background data is from 1989.	Good level of completeness, but infrastructure and land occupation / transformation not included. System expansion model includes displaced products.		Basic
				1	1	3	2		2.4

Table 21 (cont'd)

Ethanol, 95% in H20, from sugar cane, at fermentation plant/BR S - Ethanol, 95% in H20, from sugar cane, at fermentation plant/BR U	Ecoinvent	Time of publications	Brazil	Data is for the technology under study.	Data is for Brazil, but several inputs are adopted from Europe.	Data from 1998 - 2004. Data entered in 2010. Some data is based on estimations.	Good level of completeness, but facility land use / transformation not accounted for.	Most flows have moderate uncertainty. Some data is estimated.	Estimate
				1	2	4	1.5	3.5	3.1
Life Cycle Assessment of Sugarcane Ethanol and Palm Oil Biodiesel Joint Production	Journal of Biomass and Bioenergy, September 2012			Data is for the technology under study.	Data is for Sao Paulo, Brazil. Local survey taken.	Data sources from 1995-2008, study published 2012. Main data sources are primary data / surveys. No information about the dates of the surveys is available.	GHG and Energy Balance only, matches study scope. Transport between the farm and processing facility is not accounted for.		Estimate

Table 21 (cont'd)

				1	1	5	1.5		3.6
A comparative Life Cycle Assessment of PE Based on Sugar Cane and Crude Oil	Journal of Industrial Ecology 2012	1981- 2009	Brazil	Data is mostly for technology under study, but polymerization data adapted from similar data. Experimentally verified.	Most data for Brazil, but some data taken from Swedish producer Borealis.	Oldest source from 1981, but verified with experimentation for accuracy. All other sources from 1992 (emissions data) to 2009.	High degree of completeness, but facility land use not accounted for. Biogenic CO2 is also not considered in either uptake or emission because disposal by incineration is assumed.	Polymerization data taken from Borealis had to be allocated because it was for the production of both HDPE and LDPE. The division was based on energy consumption.	Estimate
				1.5	1.5	4	1.5		3.1

Table 21 (cont'd)

Bioproduction from Australian sugarcane: an environmental investigation of product diversification in an agro-industry	Journal of cleaner production Vol 39	2002-2010	Australia	Data is for technology under study.	Data for Queensland. Region represents 98% of sugarcane production for Australia, and there is little regional difference in processing.	Study first submitted in 2010. Data ranges from 2002-2010, but milling, bagasse combustion, and ethanol fermentation from sucrose are all data from 2010.	Completeness meets study scope. This is a consequential LCA, so only marginal impacts are accounted for compared to the base case. Waste treatment is not sufficiently documented.	The displaced products assumed for the system expansion approach may not be appropriate for all uses of this data.	Basic
				1	1	2.5	1.5		2.0
Life Cycle Assessment of fuel ethanol from sugar cane in Brazil	International Journal of LCA May 2009	2001-2008	Brazil	Data represents technology under study.	Data for Sao Paulo, Brazil (primary). Background data from SimaPro (generic)	Continuous data from 2001-2008. Background data from SimaPro 2003. Study published 2009.	Good level of completeness, but land use and infrastructure not accounted for.		Basic
				1	2	2	2		1.9

Table 21 (cont'd)

sugarcane, in sugar refinery	GaBi			Represents technology under study.	Some data adapted from europe. Unknown data used to modify file.	Data from "sugarcane, at farm/BR" gets a time rating of 3 (see sugarcane DQR table). Unknown data used to modify file.	Good degree of completeness, but land occupation and transformation not accounted for.		Estimate
				1	3	4	1.5		3.2

Table 22 - Soy Processing DQR

Name	Data Availability	Data Years	Data Country	Technological Rep	Geographical Rep	Time Rep	Completeness	Uncertainty	Data Quality Rating
Life cycle assessment of soybean based biodiesel production in Argentina	International Journal of LCA March 2009	2004-2007	Argentina	Represents the processing system under study. Solvent extraction technology is modeled.	Data from USA and Europe adapted to Argentina. Yields, allocation factors, natural gas, electricity consumption, electricity mix and transport distances are specific to Argentina.	Data used from 2004 and 2007. Study published 2009.	Crop storage and drying are excluded due to lack of data. Facility land use and transformation are not accounted for.		Basic
				1	2.5	2	2.5		2.3

Table 22 (cont'd)

Soya oil, at plant/kg/RER S – Soya oil, at plant/kg/RER U	Ecoinvent	1994, 1998, 1995	Europe	Generally represents European processing facilities, but some data from European manufacturing companies whose representativeness of the whole market is unknown.	Data from Europe and Switzerland used to model Europe.	Main data sources are from 1994, 1998, and 1995. Data entered in 2004.	Land use is claimed to be represented in the documentation, but no flows are present for this input. Process water is also not included.	Moderate to high uncertainty is present for all flows.	Basic
				2	2	2	2	4	3.1
Soybean oil, at oil mill/BR S - Soybean oil, at oil mill/BR U	Ecoinvent	1998-2005 Literature sources	Brazil	Data for soy oil extraction process.	Data adapted to Brazil from US study (similar production conditions).	Data sources from 1998-2005 (literature) Data entered in 2006.	Facility land use not accounted for, otherwise complete.	Low to moderate uncertainty for most flows. Transport distances are estimates.	Basic
				1	3	3	1.5	2	2.5

Table 22 (cont'd)

Soy oil, refined, at plant/kg/RNA	USLCI	Unknown	North America	Data for soy oil refining	Data for North America	Energy data from "late 2000s", all other data theoretical.	only oil refining inputs, matches study scope. Infrastructure and facility land use not accounted for.		Basic
				1	1	3	1.5		2.3
Soybean oil, crude, degummed, at plant	USLCI	2010, unknown	North America	Data for soy oil extraction process.	Data for North America	Data from Omni Tech 2010, data from NOPA date unknown. NOPA data is for water and processing chemicals	Soy oil extraction only, meet study scope, but Infrastructure not accounted for, facility land use not accounted for, and waste treatment is dummy process.		Basic
				1	1	3	2		2.4

Table 22 (cont'd)

Soybean oil, at oil mill/US S - Soybean oil, at oil mill/US U	Ecoinvent	1998-2005 Literature sources	USA	Data represents process under study. Solvent extraction modeled.	Data for the USA.	Data sources from 1998-2005 (literature) Data endted in 2006.	Facility land use not accounted for, otherwise complete.	Low to moderate uncertainty for most flows. Transport distances are estimates.	Basic
				1	1	3	1.5	2	2.3
Soy biodiesel, production , at plant	USLCI	2010, 1998, 2001	North America	Data represents process under study.	Data for North America	Data from 2010, 1998, and 2001. File created 2011.	Process chemicals are dummy processes, infrastructure and facility land use not accounted for, waste treatment not included.		Basic
				1	1	3	2.5		2.4

Appendix F: Data Summary Table

Table 23 – Raw Agricultural Data Summary

Name	Data Availability	Allocation*	Details	Includes	Data Years	Data Country
Barley straw extensive, at farm/CH S – Barley straw extensive, at farm/CH U	Ecoinvent	10%	1kg barley grains extensive, at farm respective barley straw extensive, at farm, both w/ 15% moisture content. 89.9% economic allocation to grains.	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilizers, pesticides, and seed as well as their transports to the regional processing center (10km) are considered. Direct emissions on the field also included.	1996-2003	Swiss Lowlands

Table 23 (cont'd)

Barley straw IP, at farm/CH S – Barley straw IP, a t farm/CH U	Ecoinvent	10%	1kg barley grains IP, at farm respective barley straw IP, at farm, both w/ 15% moisture content. 89.9% economic allocation to grains.	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilizers, pesticides, and seed as well as their transports to the regional processing center (10km) are considered. Direct emissions on the field also included.	1996-2003	Swiss Lowlands
Barley straw organic, at farm/CH S - Barley straw organic, at farm/CH U	Ecoinvent	9%	1kg barley grains organic, at farm respective barley straw organic, at farm, both w/ 15% moisture content. 91.3% economic allocation to grains.	Soil cultivation, sowing, weed control, fertilization, harvest and grain drying. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilizers, pesticides, and seed as well as their transports to the regional processing center (10km) are considered. Direct emissions on the field also included.	1996-2003	Swiss Lowlands

Table 23 (cont'd)

Corn stover, at field/kg/US	USLCI	0%	Corn, Whole Plant, at Field	Seed production, tillage, fertilizer and pesticide application, crop residue management, Irrigation, Harvesting		USA
Cotton straw, at field/kg/US	USLCI	0%	1 planted acre for 1 year. Harvested acres are 84% of the planted acres. The impacts of producing 1 kg of seed are considered = to producing 1 kg lint. Only consumptive use of water taken into account.	Seed production, tillage, fertillizer and pesticide application, crop residue management, Irrigation, Harvesting	1998-2000	USA

Table 23 (cont'd)

Jute stalks, from fibre production, integrated system, at farm/IN S - Jute stalks, from fibre production, integrated system, at farm/IN U	Ecoinvent	100 %	Production of Jute delivers the coproducts jute fibers, irrigated system, at farm and jute stalks, from fiber production, irrigated system at farm. Allocation based on economical and mass criteria.	Manual cultivation of Jute from conventional production standards. Cultivation, pesticides, mineral fertilizer, harvest, loading for transport and extraction of fibers after retting process.		India
Jute stalks, from fibre production, refined system, at farm/IN S - Jute stalks, from fibre production, refined system, at farm/IN U	Ecoinvent	100 %	Production of jute delivers the coproducts jute fibers, refined system, at farm and jute stalks, from fiber production, refined system at farm. Allocation based on economical and mass criteria.	Manual cultivation of Jute from conventional production standards. Cultivation, pesticides, mineral fertilizer, harvest, loading for transport and extraction of fibers after retting process.		India

Table 23 (cont'd)

Kenaf stalks, from fibre production, at farm/IN S - Kenaf stalks, from fibre production, at farm/IN U	Ecoinvent	100 %	Production of kenaf delivers the co-products "kenaf fibres" and "kenaf stalks." Allocation was based on economical and mass criteria.	Manual cultivation of Kenaf from conventional production standards. Cultivation, pesticides, mineral fertilizer, harvest, loading for transport and extraction of fibers after retting process.		India
Potato leaves, at field/kg/US	USLCI	0%	Potato, whole plant, at field. 1 planted acre for 1 year	seed production, tillage, fertilizer, pesticide, crop residue management, irrigation, harvesting	1998-2000	USA
Rapeseed residues, at field/kg/US	USLCI	0%	1 planted acre for 1 year, harvested acres are 97% of planted acres. Only comsumptive use of water taken into account.	seed production, tillage, fertilizer, pesticide, crop residue management, irrigation, harvesting. All impacts are allocated to the rape seed, and none to the residues.	1998-2000	US and European averages

Table 23 (cont'd)

Rice straw, at field/kg/US	USLCI	0%	Farming of rice on 1 plant acre for 1 year. Harvested acres are 99% of planted acres. Impacts of producing 1 kg seed are assumed to be equal to producing 1 kg grain. Only consumptive use of water is taken into account.	Seed production, tillage, fertilizer and pesticide application, crop residue management, irrigation and harvesting. Only consumptive use of water taken into account.	1998-2000	USA
Rye straw conventional, at farm/RER S - Rye straw conventional, at farm/RER U	Ecoinvent	10%	Cultivation of Rye delivers the co-products rye grains and baled rye straw. 1 ha cultivated w/ rye. Allocation based on economic criteria. 9.7% to straw. Emissions of N2O and NH3 to air and the emissions of nitrate to water are calculated w/ standard factors from Nemecek et at. 2004.	materials, energy uses, infrastructure and emissions.		Europe

Table 23 (cont'd)

Rye straw extensive, at farm/CH S – Rye straw extensive, at farm/CH U	Ecoinvent	10%	Production of 1 kg rye straw extensive, at farm. Economic allocation 90.3% to grains (see report for exceptions).	soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilizers, pesticides, and seed as well as their transports to the regional processing center (10km) are considered. Direct emissions on the field included.	1996-2003	Swiss Lowlands
Rye straw IP, at farm/CH S – Rye straw IP, at farm/CH U	Ecoinvent	10%	Production of 1 kg rye straw IP, at farm. Economic allocation 90.3% to grains (see report for exceptions).	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilizers, pesticides, and seed as well as their transports to the regional processing center (10km) are considered. Direct emissions on the field included.	1996-2003	Swiss Lowlands

Table 23 (cont'd)

Rye straw orgainic, at farm/ CH S - Rye straw orgainic, at farm/CH U	Ecoinvent	8%	Production of 1 kg rye straw organic, at farm. Economic allocation 91.9% to grains (see report for exceptions).	soil cultivation, sowing, weed control, fertilization, harvest and grain drying. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilizers, pesticides, and seed as well as their transports to the regional processing center (10km) are considered. Direct emissions on the field included.	1996-2003	Swiss Lowlands
Soybean residues, at field/kg/US	USLCI	0%	1 planted acre for 1 year, harvested acres are 98% of planted acres. Only consumptive use of water taken into account.	Seed production, tillage, fertilizer and pesticide application, crop residue management, irrigation and harvesting. Only consumptive use of water taken into account.	1998-2000	USA
Straw IP, at farm/CH S - Straw IP, at farm/CH U	Ecoinvent	100 %	Production mix for integrated straw for Switzerland			Swiss Lowlands

Table 23 (cont'd)

Straw organic, at farm/CH S	Ecoinvent	100 %	Production mix for organic straw for Switzerland			Swiss Lowlands
Straw, from farm	LCA Food DK	100 %				Denmark

Table 23 (cont'd)

Straw, from straw areas, at field/CH S – Straw, from straw areas, at field/CH U	Ecoinvent	100 %	Cultivation of straw on a straw area.	included steps are harvest and loading for transport		Swiss Lowlands
Sweet sorghum stem, at farm/CN U - Sweet sorghum stem, at farm/CH S	Ecoinvent	100 %	1 ha cultivated with sweet sorghum. Emissions of N2O and NH3 to air are calculated with standard mineral fertilizers from Nemecek et al. Emission of nitrate to water calculated with nitrogen loss factor of 32%. Allocation based on economic criteria.			China

Table 23 (cont'd)

Wheat straw extensive, at farm/CH S - Wheat straw extensive, at farm/CH U	Ecoinvent	8%	1kg wheat grains extensive, at farm respectively wheat straw extensive, at farm. Both with a moisture content of 15%. 92.5% allocated to grain.	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and housing included. Inputs of fertilizers, pesticides and seed as well as grain transports to the regional processing center (10km) are considered. The direct emissions on the field are also included.	1996-2003	Swiss Lowlands
Wheat straw IP, at farm/CH S – Wheat straw IP, at farm CH U	Ecoinvent	8%	1kg wheat grains IP, at farm respectively wheat straw IP, at farm. Both with a moisture content of 15%. 92.5% allocated to grain	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and housing included. Inputs of fertilizers, pesticides and seed as well as grain transports to the regional processing center (10km) are considered. The direct emissions on the field are also included.	1996-2003	Swiss Lowlands

Table 23 (cont'd)

Wheat straw organic, at farm/CH S - Wheat straw organic, at farm/CH U	Ecoinvent	7%	1kg wheat grains IP, at farm respectively wheat straw IP, at farm. Both with a moisture content of 15%. 93.1% allocated to grain.	Soil cultivation, sowing , weed control, harvest and grain drying. Machine infrastructure and housing included. Inputs seed as well as grain transports to the regional processing center (10km) are considered. The direct emissions on the field are also included.	1996-2003	Swiss Lowlands

Table 23 (cont'd)

Spring wheat straw, production, average, US, 2022	USLCI	15%	Wheat production based on US average yields and practices extrapolated from historic data to 2022. Includes all crop production processes from field preparation to crop maturity. Infrastructure, maintenance, and construction of facilities and equipment is included. Harvest and storage is not included. Grain and components are assumed to be at field-dry conditions of 15% moisture. Multiple output process has been reviewed by Dr. Dwayne Westfall, Dept. Soil and Crop Sciences, Colorado State University. Date of review Sept 10 - 30 2008. Data from NASS where available. Projections based on historic data. Extrapolation of historic data to 2022 estimates. Mass based between straw and grain.			North America
spring wheat straw, ground and stored, 2022	USLCI	12%	1 metric ton of wheat straw, dried to 12% moisture			North America

Table 23 (cont'd)

spring wheat straw, carted, 2022	USLCI		Crop Production - Wheat Farming			North America
winter wheat straw, ground and stored	USLCI	12%	Crop Production - Wheat Farming			North America

Table 23 (cont'd)

Winter wheat straw, production, average, US, 2022	USLCI	15%	Wheat production based on US average yields and practices extrapolated from historic data to 2022. Includes all crop production processes from field preparation to crop maturity. Infrastructure, maintenance, and construction of facilities and equipment is included. Harvest and storage is not included. Grain and components are assumed to be at field-dry conditions of 15% moisture. Multiple output process has been reviewed by Dr. Dwayne Westfall, Dept Soil and Crop Sciences, Colorado State University. Date of review Sept 10 - 30 2008. Data from NASS where available. Projections based on historic data. Extrapolation of historic data to 2022 estimates. Mass based between straw and grain. Biomass Production: 12/08 Incremental Allocation		2022	North America

Table 23 (cont'd)

Winter wheat straw, carted	USLCI		Crop Production - Wheat Farming			North America
Wheat straw, at field/kg/US	USLCI	0%	1 planted acre for 1 year. Harvested acres are 85% of the planted acres. The impacts of producing 1 kg of seed are considered = to producing 1 kg grain. Only consumptive use of water taken into account.	Seed production, tillage, fertilizer and pesticide application, crop residue management, Irrigation, Harvesting	1998-2000`	USA
Barley grains conventional, Barrios, at farm/ FR S – Barley grains conventional, Barrios, at farm/ FR U	Ecoinvent	100 %	1 kg barley grains conventional, at farm.	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and machine shelter included. Inputs of fertilizers, pesticides, and seed and their transports to the farm are considered. The direct emissions on the field are also included. System boundary at farm gate.	2000-2004	Barrios, France

Table 23 (cont'd)

Barley grains conventional, Castilla-y-Leon, at farm/ES S - Barley grains conventional, Castilla-y-Leon, at farm/ES U	Ecoinvent	100 %	1 kg barley grains conventional, at farm.	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and machine shelter included. Inputs of fertilizers, pesticides, and seed and their transports to the farm are considered. The direct emissions on the field are also included. System boundary at farm gate.	2000-2004	Castilla-y-Leon, Spain
Barley grains conventional, Saxony-Anhalt, at farm/ DE S - Barley grains conventional, Saxony-Anhalt, at farm/ DE U	Ecoinvent	100 %	1 kg barley grains conventional, at farm.	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and machine shelter included. Inputs of fertilizers, pesticides, and seed and their transports to the farm are considered. The direct emissions on the field are also included. System boundary at farm gate.	2000-2004	Saxony-Anhalt, Germany

Table 23 (cont'd)

Barley grains extensive, at farm/CH S - Barley grains extensive, at farm/CH	Ecoinvent	90%	1 kg barley grains extensive and barley straw extensive. Economic allocation factor of 89.9% to grains.	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and machine shelter included. Inputs of fertilizers, pesticides, and seed and their transports to the regional processing center (10 km) are considered. The direct emissions on the field are also included. System boundary at farm gate.	1996-2003	Swiss Lowlands
Barley grains organic, at farm/CH S – Barley grains organic, at farm/CH U	Ecoinvent	91%	1 kg barley grains organic and barley straw organic. Economic allocation factor of 91.3% to grains.	Soil cultivation, sowing, weed control, fertilization, harvest and drying of the grains. Machine infrastructure and machine shelter included. Inputs of fertilizers, seed and their transports to the regional processing center (10 km) are considered. The direct emissions on the field are also included. System boundary at farm gate.	1996-2003	Swiss Lowlands

Table 23 (cont'd)

barley grains IP, at farm	GaBi-PE	90%	1 kg barley grains IP and barley straw IP. Economic allocation with 89.9% to grains.	Seed, harvesting, grain drying, sowing, fertilization, tilling, weed control, transport, pesticide control.		Swiss Lowlands
barley extensive	GaBi-PE	90%	1 kg barley grains extensive and barley straw extensive. Economic allocation with 89.9% to grains.	Seed, harvesting, grain drying, sowing, fertilization, tilling, weed control, transport, pesticide control.		Swiss Lowlands
barley IP	GaBi-PE	90%	1 kg barley grains IP and barley straw IP. Economic allocation with 89.9% to grains.	Seed, harvesting, grain drying, sowing, fertilization, tilling, weed control, transport, pesticide control.		Swiss Lowlands
barley organic	GaBi-PE	91%	1 kg barley grains organic and barley straw organic. Economic allocation factor of 91.3% to grains.	Seed, harvesting, grain drying, sowing, fertilization, tilling, weed control, transport.		Swiss Lowlands

Table 23 (cont'd)

Carbon footprint of canola and mustard as a function of the rate of N Fertilizer	International Journal of LCA January 2012		Carbon footprint of oilseed crops grown in semi-arid great plains	CO_2 equivalents from agricultural activities (fertilizer, pesticides, herbicides, diesel for machines etc.).		USA (Northern Planes)
Corn, at farm/US S – Corn, at farm/US U	Ecoinvent	100 %	1 kg corn grain fictional unit (water content 14%, carbon content .375 kg/kg fresh mass, biomass energy content 15.9 MJ/kg fresh mass, Yield 9315 kg/ha)	includes cultivation of corn in the USA including use of diesel, machines, fertilizers, and pesticides		Modeled for USA
corn, whole plant, at field	USLCI		Harvested acres represent 91% of the planted acres. The impacts of producing 1kg seed are assumed to be equal to producing 1 kg grain. Only consumptive use of water taken into account.			USA

Table 23 (cont'd)

Corn, at field/kg/US	USLCI	100 %	Corn on 1 planted acre for 1 year (yield 3421 kg)	Includes seed production tillage fertilizer and pesticide application, crop residue management, irrigation and harvesting		USA
Grain maize IP, at farm/CH S – Grain maize IP, at farm/CH U	Ecoinvent	100 %	1 kg grain maize IP at form with moisture content of 14%. Fresh matter yield/ ha 9279kg. Average production in Swiss lowlands with integrated production. 1996-2003 data collection	Includes the processes of soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and shed for machine sheltering is included. Inputs of fertilizers, pesticides and seeds as well as their transports to the regional processing center (10km), and direct emissions on the field.		Swiss lowlands

Table 23 (cont'd)

Grain maize organic, at farm/CH S – Crain maize organic, at farm/CH U	Ecoinvent	100 %	1 kg grain maize IP at form with moisture content of 14%. Fresh matter yield/ ha 9279kg. Average production in Swiss lowlands with integrated production. 1996-2003 data collection	Includes the processes of soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and shed for machine sheltering is included. Inputs of fertilizers, pesticides and seeds as well as their transports to the regional processing center (10km), and direct emissions on the field.		Swiss Lowlands
Silage maize IP, at farm/CH S – Silage maize IP, at farm/CH U	Ecoinvent	100 %	1 kg silage maize IP, at farm.	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilizers, pesticides, and seed as well as their transports to the farm are considered. Direct emissions on the field are also included.	1996-2003	Swiss Lowlands

Table 23 (cont'd)

Corn grain, at harvest in (year), at farm 85-91% moisture (state)	LCA Commons		LCA Commons has very specific datasets for each of the states listed for multiple years. Not all states have data for all years.	Fertilizer, water, land use and conversion, transportation, tilling, harvest, pesticide and herbicide use.	1995-2001, 2005	USA: Various States
Silage maize organic, at farm/CH S - Silage maize organic, at farm/CH U	Ecoinvent	100 %	1 kg silage maize organic, at farm.	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilizers, pesticides, and seed as well as their transports to the farm (1km) are considered. Direct emissions on the field are also included.	1996-2003	Swiss Lowlands

Table 23 (cont'd)

Biowaste, at collection point/CH S - Biowaste, at collection point/CH U	Ecoinvent	100 %	Transport processes required to collect biowaste from households and deliver to treatment plant. Credit is given for extraction of CO2 from atmosphere.	Transport as part of municipal waste collection scheme. Distance 15km for municipal waste and 17km from collection point to treatment center. 40% dry matter, 70% organic matter		Swiss Lowlands
Substitutable biodiesel feedstocks for the UK: a review of sustainability issues with reference to the UK RTFO	Journal of Cleaner Production 2009		Data for Jatropha, soy, palm oil, rape seed oil, and used cooking oil for production of biodiesel. Reports carbon footprint and GHG savings (except for Jatropha). Includes GHG from direct and indirect land use change.	GHG and carbon footprint only. Land use changes included in this calculation.	2009	UK
Oat, organic, from farm	LCA Food DK	100 %				

Table 23 (cont'd)

Oats, at harvest in 2005, at farm 86-92% moisture (state)	LCA Commons		LCA Commons has very specific datasets for each of the states listed for 2005.	Fertilizer, water, land use and conversion, transportation, tilling, harvest, pesticide and herbicide use.	2005	USA: Various States
Oat, conventional, from farm	LCA Food DK	100 %		Produced on farm type 21		Denmark
Substitutable biodiesel feedstocks for the UK: a review of sustainability issues with reference to the UK RTFO	Journal of Cleaner Production 2009		Data for Jatropha, soy, palm oil, rape seed oil, and used cooking oil for production of biodiesel. Reports carbon footprint and GHG savings (except for Jatropha). Includes GHG from direct and indirect land use change.	GHG and carbon footprint only. Land use changes included in this calculation.	2009	UK

Table 23 (cont'd)

Potato, at field/kg/US	USLCI	100 %	Potato, whole plant, at field. 1 planted acre for 1 year	seed production, tillage, fertilizer, pesticide, crop residue management, irrigation, harvesting	1998-2000	USA
potato, whole plant, at field	USLCI		Harvested acres are 97% of planted acres. Impacts of 1kg seed are assumed to equal those of 1 kg potatoes. Only consumptive use of water taken into account.			North America
Potatoes IP, at farm/CH S – Potatoes IP, at farm/CH U	Ecoinvent	100 %	1 kg potatoes IP, at farm with moisture content of 78%	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control and harvest. Machine infrastructure and shed for machine sheltering included. Inputs of fertilizers, pesticides and seed as well as their transports to the farm (1km). Direct field emissions included.	1996-2003	Swiss lowlands

Table 23 (cont'd)

Potatoes organic, at farm/CH U – Potatoes organic, at farm/CH S	Ecoinvent	100 %	1 kg of potatoes organic, at farm with moisture content of 78%	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control and harvest. Machine infrastructure and shed for machine sheltering included. Inputs of fertilizers, pesticides and seed as well as their transports to the farm (1km). Direct field emissions included.	1996-2003	Swiss lowlands
Potatoes, at farm/US S – Potatoes, at farm/US U	Ecoinvent	100 %	1 kg potatoes, at farm with moisture content of 78%.	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, irrigation and harvest. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilizers, pesticides, and seed as well as their transports to the farm are considered. The direct emissions on the field are included and the system boundary is the farm gate.	2001-2006	USA

Table 23 (cont'd)

Environmental burdens of producing bread wheat, oilseed rape, and potatoes in England and wales using simulation and system modeling	International Journal of Life Cycle Assessment September 2010		Fictional unit is 1 ton marketable fresh weight. What is marketable as food < what can be used for ethanol production. Long term approach to soil nutrients.	Crop storage, cooling and drying prior to sale. System boundary is the farm gate. Energy, pesticides, herbicides, and fertilizer, land occupation, and irrigation water included	2010	England / Wales
Energy consumption and CO2 emission analysis of potato production based on different farm size levels in Iran	Journal of Cleaner Production Vol 33		Production of potatoes in Iran, scenarios based on farm size. Energy and GHG reported.	Machinery, human labor, diesel, biocide, fertilizer, water for irrigation, seed.	2012	Iran
Potatoes, from farm	LCA Food DK	100 %	Weighted average of the marginal production at 28 farm types	Soil cultivation, sowing, fertilizing, plant protection, harvesting, making silage and transport of crops. Pesticides and machine and building construction and maintenance also not included.		Denmark

Table 23 (cont'd)

Rape seed conventional, at farm/DE S – Rape seed conventional, at farm /DE U	Ecoinvent	100 %	Cultivation of rape in Germany modeled with data from literature	Use of diesel, machines, fertilizers, and pesticides	1996, 2001, 2006	Germany
Rape seed conventional, Barrios, at farm/FR S – Rape seed conventional, Barrios, at farm/FR U	Ecoinvent	100 %	1 kg rape seed conventional, Barrios, at farm (10% moisture content)	soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and a shed for machine sheltering. System boundary is at farm gate. Seed inputs and material transport	2000-2004	Barrios, France

Table 23 (cont'd)

Rape seed conventional, Saxony-Anhalt, at farm/DE S - Rape seed conventional, Saxony-Anhalt, at farm/DE U	Ecoinvent	100 %	1 kg rape seed conventional, Saxony-Anhalt, at farm (9% moisture content).	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and a shed for machine sheltering. System boundary is at farm gate. Seed inputs and material transport	2000-2004	Saxony-Anhalt, Germany
Rape seed extensive, at farm/CH S - Rape seed extensive, at farm/CH U	Ecoinvent	100 %	1 kg rape seed extensive, at farm (6% moisture content)	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and drying of the grains. Machine infrastructure, shed for machine sheltering, inputs for seeds, transport of materials to regional processing center (10km). Direct emissions on the field.	1996-2003	Swiss lowlands

Table 23 (cont'd)

Rape seed IP, at farm/CH S - Rape seed IP, at farm/CH U	Ecoinvent	100 %	1 kg rape seed IP, at farm with moisture content of 6%.	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and sheltering, inputs of fertilizers, pesticides and seed as well as their transports to the regional processing center (10km), direct emissions on the field.	1996-2003	Swiss lowlands
Rape seed, at farm/US S – Rape seed, at farm/US U	Ecoinvent	100 %	1 kg rape seed, at farm with 6% moisture content. Yield is given as fresh matter, 12% moisture content. Water for irrigation is pumped form 48 m depth w/ electric pumps.	Soil cultivation, sowing, weed control, fertilization, pesticides and pathogen control, harvest. Machine infrastructure and sheltering, inputs of fertilizers, pesticides and seed as well as their transports to the farm, direct emissions on the field.	2001-2006	USA
Rape seed, organic, at field/CH S - Rape seed, organic, at field/CH U	Ecoinvent	100 %	1 kg rape seed, organic, at farm with 6% moisture. Fresh matter yield at 6% moisture given.	soil cultivation, fertilization, harvest, drying and transport to farm		Swiss lowlands

Table 23 (cont'd)

Rapeseed, at field/kg/US	USLCI	100 %	1 planted acre for 1 year, harvested acres are 97% of planted acres. Only consumptive use of water taken into account.	seed production, tillage, fertilizer, pesticide, crop residue management, irrigation, harvesting	1998-2000	USA and European average practices
Environmental burdens of producing bread wheat, oilseed rape, and potatoes in England and wales using simulation and system modeling	International Journal of Life Cycle Assessment		Functional unit is 1 ton marketable fresh weight. What is marketable as food < what can be used for ethanol production. Long term approach to soil nutrients.	Crop storage, cooling and drying prior to sale. System boundary is the farm gate. Energy, pesticides, herbicides, and fertilizer, land occupation, and irrigation water included	2010	England / Wales

Table 23 (cont'd)

Substitutable biodiesel feedstocks for the UK: a review of sustainability issues with reference to the UK RTFO	Journal of Cleaner Production 2009		Data for Jatropha, soy, palm oil, rape seed oil, and used cooking oil for production of biodiesel. Reports carbon footprint and GHG savings (except for Jatropha). Includes GHG from direct and indirect land use change.	GHG and carbon footprint only. Land use changes included in this calculation.	2009	UK
rapeseed, whole plant, at field	USLCI		1 planted acre for 1 year, harvested acres are 97% of planted acres. Only consumptive use of water taken into account.			North America
Rice grain, at field/kg/US	USLCI	100 %	Harvested acres are 99% of planted acres. Impacts of 1kg seed are assumed to equal those of 1 kg grain. Only consumptive use of water taken into account.	seed production, tillage, fertilizer, pesticide, crop residue management, irrigation, harvesting	1998-2000	USA
Rice; at harvest in 2006 at farm 63-90% moisture (state)	LCA Commons		LCA Commons has specific data for each state listed for 2006.	Fertilizer, water, land use and conversion, transportation, tilling, harvest, pesticide and herbicide use.	2006	USA: Various States

Table 23 (cont'd)

Rice, at farm/US S – Rice, at farm/US U	Ecoinvent	100 %	1 kg rice at farm. Yield given at 21% moisture	Soil cultivation, sowing, weed control, pest and pathogen control, irrigation and harvest. Machine infrastructure and shelter included. Inputs of fertilizers, pesticides, and seed as well as their transports to the farm are considered. The direct emissions on the field are also included. System boundary is at the farm gate.	2001-2006	USA
Rye grains conventional, at farm/RER S – Rye grains conventional, at farm/RER U	Ecoinvent	90%	1 ha cultivated with sweet rye. Emissions of N2O and NH3 to air are calculated with standard mineral fertilizers from Nemecek et al. Emission of nitrate to water calculated with the method described in Nemecek et al. Allocation based on economic criteria 90.3% grains, 9.7% straw.	Cultivation of rye in Europe including materials, energy uses, infrastructure, and emissions.	Time of literature publications (various)	Europe

Table 23 (cont'd)

Rye grains extensive, a t farm/CH S - Rye grains extensive, at farm/CH U	Ecoinvent	90%	1 kg rye grains extensive. Economic allocation with factor of 90.3% to grains.	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and shed for machine sheltering included, as well as the inputs for fertilizers, pesticides and seed. Grain transports to the regional processing center (10km) are considered. Direct emissions on the field are also included.	1996-2003	Swiss Lowlands
Rye grains IP, at farm/CH S - Rye grains IP, at farm/CH U	Ecoinvent	90%	1 kg rye grains IP. Economic allocation with factor of 90.3% to grains.	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and shed for machine sheltering included, as well as the inputs for fertilizers, pesticides and seed. Grain transports to the regional processing center (10km) are considered. Direct emissions on the field are also included.	1996-2003	Swiss Lowlands

Table 23 (cont'd)

Rye grains organic, at farm/CH S - Rye grains organic, at farm/CH U	Ecoinvent	92%	1 kg rye grains organic. Economic allocation with factor of 91.9% to grains.	Soil cultivation, sowing, weed control, fertilization, harvest and grain drying. Machine infrastructure and shed for machine sheltering included, as well as the inputs for fertilizers, and seed. Grain transports to the regional processing center (10km) are considered. Direct emissions on the field are also included.	1996-2003	Swiss Lowlands
Sweet sorghum grains, at farm/CN S – Sweet sorghum grains, at farm/CN U	Ecoinvent	100 %	1 ha cultivated with sweet sorghum. Emissions of N2O and NH3 to air are calculated with standard mineral fertilizers from Nemecek et al. Emission of nitrate to water calculated with nitrogen loss factor of 32%. Allocation based on economic criteria.	Diesel, machines, fertilizers and pesticides		China

Table 23 (cont'd)

sweet sorghum	Ecoinvent		1 ha cultivated with sweet sorghum. Emissions of N2O and NH3 to air are calculated with standard mineral fertilizers from Nemecek et al. Emission of nitrate to water calculated with nitrogen loss factor of 32%. Allocation based on economic criteria.	Diesel, machines, fertilizers and pesticides		China
Soybean grains, at field	USLCI		"Carbon Sequestration should be accounted for after the product is built in its LCA model, and should be included depending on the use of end of life fate of that product. For example, a soy-based resin may retain the sequestered carbon indefinitely, while a soy-based biodiesel releases the sequestered carbon at use phase" (USLCI).			USA
Soy bean, from farm	LCA Food DK	100 %				Argentina

Table 23 (cont'd)

Soy beans IP, at farm/CH S – Soy beans IP at farm/CH U	Ecoinvent	100 %	1 kg of soy beans IP, at farm with a moisture content of 11%	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and housing. Inputs for fertilizers, pesticides and seed as well as their transports to the regional processing center (10km) are considered, direct emissions on the field also included.	1996-2003	Swiss lowlands
Soy beans organic, at farm/CH S – Soy beans organic, at farm/CH U	Ecoinvent	100 %	1 kg soy beans organic, at farm with moisture content of 11%	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and housing. Inputs for fertilizers, pesticides and seed as well as their transports to the regional processing center (10km) are considered, direct emissions on the field also included.	1996-2004	Swiss lowlands

Table 23 (cont'd)

Soybeans, at field/kg/US	USLCI	100 %	1 planted acre for 1 year	Seed production, tillage, fertilizer and pesticide application, crop residue management, irrigation and harvesting. Only consumptive use of water taken into account.	1998-2000	USA
Soybeans, at farm/BR S - Soybeans, at farm/BR U	Ecoinvent	100 %	1 kg soybeans with moisture content of 11%. Modeled with data from literature, some data extrapolated from Europe (production of fertilizers and pesticides), and Switzerland (machine use). Transports modeled for standard distances.	Use of diesel, machines, fertilizers, and pesticides	Time of literature publications (various)	Brazil
Soybeans; at harvest in (year); at farm; 85-92% moisture (state)	LCA Commons		LCA Commons has specific data for each state listed for various years. Not all states are available for all years.	fertilizer, water, land use and conversion, transportation, tilling, harvest, pesticide and herbicide use, seeding	1996-2000, 2002, 2006	USA: Various States

Table 23 (cont'd)

Substitutable biodiesel feedstocks for the UK: a review of sustainability issues with reference to the UK RTFO	Journal of Cleaner Production 2009		Data for Jatropha, soy, palm oil, rape seed oil, and used cooking oil for production of biodiesel. Reports carbon footprint and GHG savings (except for Jatropha). Includes GHG from direct and indirect land use change.	GHG and carbon footprint only. Land use changes included in this calculation.	2009	UK
Soybeans, at farm /US S – Soybeans, at farm /US U	Ecoinvent	100 %	1 kg soybeans with moisture content of 11%. Modeled with data from literature, some data extrapolated from Europe (production of fertilizers and pesticides), and Switzerland (machine use). Transports modeled for standard distances.	Use of diesel, machines, fertilizers, and pesticides	Time of literature publications (various)	USA, with some data from Europe and Switzerland
Sugar beet, from farm	LCA Food DK	100 %	Weighted averages of the marginal production at 28 farm types			Denmark

Table 23 (cont'd)

Sugar beets IP, at farm/CH S – Sugar beets IP, at farm/CH U	Ecoinvent	100 %	1 kg sugar beets IP, at farm with a moisture content of 77%	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control and harvest. Machine infrastructure and housing included. Inputs of fertilizers, pesticides and seed as well as their transports to the farm (1km) are considered. Direct emissions on the field also included.	1996-2003	Swiss lowlands
Sugarcane, at farm/BR S – Sugarcane, at farm/BR U	Ecoinvent	100 %	Cultivation of sugar cane with 20% mechanical harvest and 80% manual harvest	diesel, machines, fertilizers, and pesticides	Time of literature publications (various)	Brazil

Table 23 (cont'd)

Life cycle assessment of Australian sugar cane production with a focus on sugarcane growing	International Journal of Life Cycle Assessment Nov 2010					Australia
A decision support tool for modifications in crop cultivation method based on LCA: a case study on GHG emissions reduction in Taiwanese sugarcane cultivation	International Journal of LCA November 2009		GHG data for the cultivation of Taiwanese sugarcane	Soil preparation, growing, harvesting, transport	2009	Taiwan

Table 23 (cont'd)

Production and energetic utilization of wood from short rotation coppice - a life cycle assessment	International Journal of Life Cycle Assessment July 2010		This study is broken into parts: 1 - production of wood (poplar chips). This is the only part applicable to this study as step 2 is the combustion of the biofuel in a medium sized car. This study assumes carbon neutrality.	Soil preparation, harvest, drying, and transport. FU = 1 oven dried ton.		
Environmental assessment of black locust based ethanol as potential	International Journal of Life Cycle Assessment June 2011					

Table 23 (cont'd)

Switchgrass, production, US, 2022	USLCI		US switchgrass production (1hectare) for 2022. Based on projections from Sokhansanj et al. 2009 and MacLaughlin and Kszos 2005. The mean switchgrass yield in the US in 2008 was estimated to be 11.3 Mg per ha, this includes both upland and lowland varieties. The projected 2022 yield was determined by the following (2022 yield = (2008 yield)*(1+.02)^14, where the 2008 yield = 11.2 Mg per hectare, 0.02 is the 2% annual yield improvement, and 14 is the number of years. The annual rate of yield increase is estimated to be 2%.	This process Includes all crop production processes from field preparation to harvest and baling. Assuming a 10-year stand. Transport and storage of bales is not included.	2022	USA
Switchgrass, harvested, wet	USLCI		Description mass of Switchgrass at 34% moisture with 20% harvest loss.			USA

Table 23 (cont'd)

Planting, switchgrass, 2022	USLCI		Includes only seed and planting	Seed, planting	2022	North America
Life cycle assessment of switchgrass derived ethanol as transport fuel	International Journal of Life Cycle Assessment		Functional unit of study is power to the wheels of a car, but separate LCA data of Switchgrass production is included. This is a 20 year crop cycle where year 1 is separated out because it has significantly different inputs.	Seeding, fertilizer, herbicide (different amounts and types for year 1 than for years 2-20).		
Wheat grains conventional, barrios, at farm/FR S – Wheat grains conventional, barrios, at farm/FR U	Ecoinvent	100 %	1 kg wheat grains conventional, Barrios w/ moisture content 14.5%	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilizers, pesticides, and seed as well as their transports to the farm are considered. Direct emissions on the field included, system boundary at farm gate.	2000-2004	Barrios, France

Table 23 (cont'd)

Wheat grains conventional, Castilla-y-Leon, at farm/ES S – Wheat grains conventional, Castilla-y-Leon, at farm/ES U	Ecoinvent	100 %	1 kg wheat grains conventional, Castilla-y-Leon w/ moisture content 15%	soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and a shed for machine sheltering are included. Inputs of fertilizers, pesticides, and seed as well as their transports to the farm are considered. Direct emissions on the field included, system boundary at farm gate.	2000-2004	Castilla-y-Leon, Spain
Wheat grains conventional, Saxony-Anhalt, at farm/ DE S -Wheat grains conventional, Saxony-Anhalt, at farm/DE U	Ecoinvent	100 %	1 kg wheat grains conventional, Saxony-Anhalt w/ moisture content 14.5%	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilizers, pesticides, and seed as well as their transports to the farm are considered. Direct emissions on the field included, system boundary at farm gate.	2000-2004	Saxony-Anhalt, Germany

Table 23 (cont'd)

Wheat grains extensive, at farm/CH S Wheat grain extensive, at farm/CH U	Ecoinvent	93%	1 kg wheat grains extensive, at farm respectively wheat straw extensive, at farm both with moisture content of 15%. 92.5% allocated to grain, remainder to straw.	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilizers, pesticides, and seed as well as their transports to the regional processing center (10km) are considered. Direct emissions on the field included, system boundary at farm gate.	1996-2003	Swiss lowlands
wheat extensive	GaBi-PE	93%	1 kg wheat grains extensive, at farm respectively wheat straw extensive, at farm both with moisture content of 15%. 92.5% allocated to grain, remainder to straw.			Swiss Lowlands

Table 23 (cont'd)

Wheat grains IP, at farm/CH S – Wheat grains IP, at farm/CH U	Ecoinvent	93%	1 kg wheat grains IP, at farm respectively wheat straw IP, at farm both with moisture content of 15%. 92.5% allocated to grains, remainder to straw.	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and grain drying. Machine infrastructure and a shed for machine sheltering are included. Inputs of fertilizers, pesticides, and seed as well as their transports to the regional processing center (10km) are considered. Direct emissions on the field included, system boundary at farm gate.	1996-2003	Swiss lowlands
wheat IP	Ecoinvent	93%	1 kg wheat grains IP, at farm respectively wheat straw IP, at farm both with moisture content of 15%. 92.5% allocated to grains, remainder to straw.			Swiss Lowlands

Table 23 (cont'd)

Wheat grains organic, at farm/CH S – Wheat grains organic, at farm/CH U	Ecoinvent	93%	1 kg wheat grains organic, at farm respectively wheat straw organic, at farm both with moisture content of 15%. 93.1% allocated to grains, remainder to straw.	Soil cultivation, sowing, weed control, fertilization, harvest and grain drying. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilizers, pesticides, and seed as well as their transports to the regional processing center (10km) are considered. Direct emissions on the field included.	1996-2003	Swiss lowlands
wheat organic	GaBi-PE	93%	1 kg wheat grains organic, at farm respectively wheat straw organic, at farm both with moisture content of 15%. 93.1% allocated to grains, remainder to straw.			Swiss Lowlands

Table 23 (cont'd)

Wheat grains, at farm/ US S - Wheat grains, at farm/US U	Ecoinvent	100 %	1 kg wheat grains, at farm w/ moisture content 15%	Soil cultivation, sowing, weed control, fertilization, pest and pathogen control, irrigation and harvest. Machine infrastructure and a shed for machine sheltering is included. Inputs of fertilizers, pesticides and seed as well as their transports to the farm are considered. The direct emissions on the field are included, system boundary at farm gate.	2001-2006	USA
Wheat grains, at field/kg/US	USLCI	100 %	1 planted acre for 1 year. Harvested acres are 85% of the planted acres. The impacts of producing 1 kg of seed are considered = to producing 1 kg grain. Only consumptive use of water taken into account.	Seed production, tillage, fertilizer and pesticide application, crop residue management, irrigation, harvesting	1998-2000	USA

Table 23 (cont'd)

wheat, at field	USLCI	100 %	1 planted acre for 1 year. Harvested acres are 85% of the planted acres. The impacts of producing 1 kg of seed are considered = to producing 1 kg grain. Only consumptive use of water taken into account.			USA
Wheat conventional, from farm	LCA Food DK	100 %				Denmark
Winter wheat; at harvest in (year); at farm; 86-90% moisture (state)	LCA Commons		LCA Commons has specific data for each state listed for various years. Not all states are available for all years.	fertilizer, water, land use and conversion, transportation, tilling, harvest, pesticide and herbicide use, seeding	1996-1998, 2000, 2004, 2009	USA: Various States

Table 23 (cont'd)

Spring wheat; exclu. Durum; at harvest in (year); at farm; 86-90% moisture (state)	LCA Commons		LCA Commons has specific data for each state listed for various years. Not all states are available for all years.	fertilizer, water, land use and conversion, transportation, tilling, harvest, pesticide and herbicide use, seeding	1996-1998, 2000, 2004, 2009	USA: Various States
Durum wheat; at harvest in (year); at farm; 88-89% moisture (state)	LCA Commons		LCA Commons has specific data for each state listed for various years. Not all states are available for all years.	fertilizer, water, land use and conversion, transportation, tilling, harvest, pesticide and herbicide use, seeding	1996-1998, 2000, 2004, 2009	California, North Dakota, Montana
Wheat, organic, from farm	LCA Food DK	100 %				Denmark

Table 23 (cont'd)

Environmental burdens of producing bread wheat, oilseed rape, and potatoes in England and Wales using simulation and system modeling	International Journal of Life Cycle Assessment September 2010		Functional unit is 1 ton marketable fresh weight. What is marketable as food < what can be used for ethanol production. Long term approach to soil nutrients.	Crop storage, cooling and drying prior to sale. System boundary is the farm gate. Energy, pesticides, herbicides, and fertilizer, land occupation, and irrigation water included	2010	England / Wales
The impact of local crops consumption on the water resources in Beijing	Journal of Cleaner Production Vol 21		Reports water consumption only for the following crops: Wheat, maize, sweet potato, soybean, groundnut, watermelon, open vegetables, covered vegetables. Water is divided into the sub categories of blue, green and gray.	Rainfall, irrigation, nitrogen application, planted area.	2011	China

Table 23 (cont'd)

System delimitation in agricultural consequential LCA: outline of methodology and illustrative case study of wheat in Denmark	International Journal of Life Cycle Assessment June 2008		GHG, eutrophication, and land occupation reported. Different fertilizer and yield scenarios are reported.	Direct N and P emissions			Denmark
*Allocation is based on economic values unless otherwise noted.							

Table 24 – Raw Agricultural Data Summary Inputs

Name	Seed Production	Transport	Diesel used on field	Farm Machine	Machine Shelter	Sowing	Tillage	Fertilizer	Weed Control	Pesticide	Crop Residue	Irrigation	Harvesting	Grain Drying	Direct Field Emissions	Crop Storage	Land Occupation	Land Transformation
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Barley straw extensive, at farm/CH S - Barley straw extensive, at farm /CH U	1	1		1	1	1	1	1	1	1			1	1	1		1	1
Barley straw IP, at farm/CH S – Barley straw IP, at farm/CH U	1	1		1	1	1	1	1	1	1			1	1	1		1	1

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Barley straw organic, at farm/CH S – Barley straw organic, at farm/CH U	1	1		1	1	1	1	1	1				1	1	1		1	1
Corn stover, at field/kg/US	1						1	1		1	1	1	1				1	
Cotton straw, at field/kg/US	1						1	1		1	1	1	1				1	

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Jute stalks, from fibre production, integrated system, at farm/IN S - Jute stalks, from fibre production, integrated system, at farm/IN U							1	1		1			1				1	1
Jute stalks, from fibre production, refined system, at farm/IN S – Jute stalks, from fibre production, refined system, at farm/IN U							1	1		1			1				1	1
Kenaf stalks, from fibre production, at farm/IN S - Kenaf stalks, from fibre production, at farm/IN U							1	1		1			1				1	1

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Potato leaves, at field/ kg/US	1						1	1		1	1	1	1				1	
Rapeseed residues, at field/kg/US	1						1	1		1	1	1	1				1	
Rice straw, at field/kg/US	1						1	1		1	1	1	1				1	
Rye straw conventional, at farm/RER S – Rye straw conventional, at farm/RER U																	1	1

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Rye straw extensive, at farm/CH S – Rye straw extensive, at farm/CH U	1	1		1	1	1	1	1	1	1			1	1	1		1	1
Rye straw IP, at farm/CH S - Rye straw IP, at farm/CH U	1	1		1	1	1	1	1	1	1			1	1	1		1	1
Rye straw organic, at farm/CH S – Rye straw organic, at farm/CH U	1	1		1	1	1	1	1	1				1	1	1		1	1
Soybean residues, at field/ kg/US	1						1	1		1	1	1	1				1	

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Straw IP, at farm/ CH S – Straw IP, at farm /CH U																	1	1
Straw organic, at farm /CH S																	1	1
Straw, From farm																		
Straw, from Straw areas, at field/CH S - Straw, from straw areas, at field/CH U													1				1	1
Sweet sorghum stem, at farm/CN U - Sweet sorghum Stem at at farm/CH S																	1	1

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Wheat straw extensive, at farm/CH S – Wheat straw extensive, at farm/CH U	1	1		1	1	1	1	1	1	1			1	1	1		1	1
Wheat straw IP, farm/CH S – Wheat straw IP, at farm CH U	1	1		1	1	1	1	1	1	1			1	1	1		1	1
Wheat straw organic, at farm/CH S – Wheat straw organic, at farm/CH U	1			1	1	1	1		1				1	1	1		1	1
Spring wheat straw, production, average, US, 2022																	1	
spring wheat straw, ground and stored, 2022																	1	

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
spring wheat straw, carted, 2022																	1	
winter wheat straw, ground and stored																	1	
Winter wheat straw, production, average, US, 2022																	1	
Winter wheat straw, carted																	1	
Wheat straw, at field /kg/US	1						1	1		1	1	1	1				1	

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Barley grains conventional, Barrios, at farm/ FR S – Barley grains conventional, Barrios, at farm/ FR U	1	1		1	1	1	1	1	1	1			1	1	1		1	1
Barley grains conventional, Castilla-y-Leon, at farm/ES S - Barley grains conventional, Castilla-y-Leon, at farm/ES U	1	1		1	1	1	1	1	1	1			1	1	1		1	1
Barley grains conventional, Saxony-Anhalt, at farm/ DE S - Barley grains conventional, Saxony-Anhalt, at farm/ DE U	1	1		1	1	1	1	1	1	1			1	1	1		1	1
Barley grains extensive, at farm /CH S - Barley grains extensive, at farm /CH	1	1		1	1	1	1	1	1	1			1	1	1		1	1

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Barley grains organic, at farm/CH S - Barley grains organic, at farm/CH U	1	1		1	1	1	1	1	1				1	1	1		1	1
Barley grains IP, at farm	1	1				1	1	1	1	1			1	1			1	1
Barley extensive	1	1				1	1	1	1	1			1	1			1	1
Barley IP	1	1				1	1	1	1	1			1	1			1	1
barley organic	1	1				1	1	1	1				1	1			1	1
Carbon footprint of canola and mustard as a function of the rate of N Fertilizer			1					1	1	1								

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Corn, at farm/US S - Corn, at farm/US U			1	1				1		1							1	1
corn, whole plant, at field																	1	
Corn, at field /kg/US	1						1	1		1	1	1	1				1	
Grain maize IP, at farm/CH S - Grain maize IP, at farm/CH U	1	1		1	1	1		1	1	1			1	1	1		1	1
Grain maize organic, at farm/CH S - Crain maize organic, at farm/CH U	1	1		1	1	1		1	1	1			1	1	1		1	1

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Silage maize IP, at farm/CH S - Silage maize IP, at farm/CH U	1	1		1	1	1		1	1	1			1	1	1		1	1
Corn grain, at harvest in (year), at farm 85-91% moisture (state)		1					1	1	1	1			1				1	1
Silage maize organic, at farm/CH S - Silage maize organic, at farm/CH U	1	1		1	1	1		1	1	1			1	1	1		1	1
Biowaste, at collection point/CH S - Biowaste, at collection point/CH U																	1	1

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Substitutable biodiesel feedstocks for the UK: a review of sustainability issues with reference to the UK RTFO													1		1		1	1
Oat, organic, from farm																		
Oats, at harvest in 2005, at farm 86-92% moisture (state)		1					1	1	1	1		1	1				1	1
Oat, conventional, from farm																		

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Substitutable biodiesel feedstocks for the UK: a review of sustainability issues with reference to the UK RTFO													1		1		1	1
Potato, at field /kg/US	1						1	1		1	1	1	1				1	
potato, whole plant, at field																	1	
Potatoes IP, at farm/CH S - Potatoes IP, at farm/CH U	1	1		1	1	1	1	1	1	1			1		1		1	1
Potatoes organic, at farm/CH U - Potatoes organic, at farm/CH S	1	1		1	1	1	1	1	1	1			1		1		1	1

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Potatoes, at farm/US S - Potatoes, at farm/US U	1	1		1	1	1	1	1	1	1		1	1		1		1	1
Environmental burdens of producing bread wheat, oilseed rape, and potatoes in England and wales using simulation and system modeling			1					1	1	1		1	1	1		1		
Energy consumption and CO2 emission analysis of potato production based on different farm size levels in Iran			1	1				1	1	1		1						
Potatoes, from farm		1				1	1	1					1			1		

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Rape seed conventional, at farm/DE S - Rape seed conventional, at farm /DE U			1	1				1		1							1	1
Rape seed conventional, Barrios, at farm/FR S – Rapeseed conventional, Barrios, at farm/FR U	1	1		1	1	1	1	1	1	1			1	1	1		1	1
Rape seed conventional, Saxony-Anhalt, at farm/DE S - Rape seed conventional, Saxony-Anhalt, at farm/DE U	1	1		1	1	1	1	1	1	1			1	1	1		1	1
Rape seed extensive, at farm/CH S – Rape seed extensive, at farm/CH U	1	1		1	1	1	1	1	1	1			1	1	1		1	1

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Rape seed IP, at farm/CH S - Rape seed IP, at farm/CH U	1	1		1	1	1	1	1	1	1			1	1	1		1	1
Rapeseed, at farm/ US S - Rapeseed, at farm /US U	1	1		1	1	1	1	1	1	1			1		1		1	1
Rapeseed, organic, at field/CH S – Rape seed, organic, at field/CH U		1					1	1					1	1			1	1
Rapeseed, at field /kg/US	1						1	1		1	1	1	1				1	
burdens of producing bread wheat, oilseed rape, and potatoes in England and wales using simulation and			1					1	1	1		1	1	1		1		

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Substitutable biodiesel feedstocks for the UK: a review of sustainability issues with reference to the UK RTFO													1		1		1	1
rapeseed, whole plant, at field																	1	
Rice grain, at field/kg/US	1		1				1	1		1	1	1	1		1		1	
Rice; at harvest in 2006 at farm 63-90% moisture (state)		1					1	1	1	1			1		1		1	1
Rice, at farm/ US S – Rice, at farm/ US U	1	1	1	1	1	1	1	1	1	1		1	1		1		1	1

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Rye grains conventional, at farm/RER S - Rye grains conventional, at farm/RER U			1														1	1
Rye grains extensive, at farm/CH S - Rye grains extensive, at farm/CH U	1	1	1	1	1	1	1	1	1	1			1	1	1		1	1
Rye grains IP, at farm/CH S – Rye grains IP, at farm/CH U	1	1	1	1	1	1	1	1	1	1			1	1	1		1	1
Rye grains organic, at farm/CH S – Rye grains organic, at farm/CH U	1	1	1	1	1	1	1	1	1				1	1	1		1	1

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Sweet sorghum grains, at farm /CN S - Sweet sorghum grains, at farm/CN U			1	1				1		1							1	1
sweet sorghum			1	1				1		1							1	1
Soybean grains, at field			1														1	
Soy bean, from farm			1															
Soy beans IP, at farm/CH S - Soy beans IP at farm/CH U	1	1	1	1	1	1	1	1	1	1			1	1	1		1	1

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Soy beans organic, at farm/CH S - Soy beans organic, at farm/CH U	1	1	1	1	1	1	1	1	1	1			1	1	1		1	1
Soybeans, at field/ kg/US	1		1				1	1		1	1	1	1				1	
Soybeans, at farm/BR S - Soybeans, at farm/BR U			1	1				1		1							1	1
Soybeans; at harvest in (year); at farm; 85-92% moisture (state)	1	1				1	1	1	1	1			1				1	1

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Substitutable biodiesel feedstocks for the UK: a review of sustainability issues with reference to the UK RTFO			1										1		1		1	1
Soybeans, at farm/US S - Soybeans, at farm/US U			1	1				1		1							1	1
Sugar beet, from farm																		
Sugar beets IP, at farm /CH S - Sugar beets IP, at farm/CH U	1	1	1	1	1	1	1	1	1	1			1		1		1	1
Sugarcane, at farm /BR S - Sugarcane, at farm /BR U		1	1	1		1	1	1		1		N/A	1				1	1

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Life cycle assessment of Australian sugar cane production with a focus on sugarcane growing	1	1	1	1		1	1	1		1		1	1				1	
A decision support tool for modifications in crop cultivation method based on LCA: a case study on GHG emissions reduction in Taiwanese sugarcane cultivation	1	1	1			1	1	1	1	1		N/A	1		1			
Production and energetic utilization of wood from short rotation coppice – a life cycle assessment																		

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Environmental assessment of black locust based ethanol as potential																		
Switchgrass, production, US, 2022						1	1						1					
Switchgrass, harvested, wet																	1	
Planting, switchgrass, 2022	1					1											1	
Life cycle assessment of switchgrass derived ethanol as transport fuel	1							1	1	1								

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Wheat grains conventional, barrios, at farm/FR S – Wheat grains conventional, barrios, at farm/FR U	1			1	1	1	1	1	1	1			1	1	1		1	1
Wheat grains conventional, Castilla-y-Leon, at farm/ES S -Wheat grains conventional, Castilla-y-Leon, at farm/ES U	1			1	1	1	1	1	1	1			1	1	1		1	1
Wheat grains conventional, Saxony-Anhalt, at farm/DE S - Wheat grains conventional, Saxony-Anhalt, at farm/DE U	1			1	1	1	1	1	1	1			1	1	1		1	1
Wheat grains extensive, at farm/CH S – Wheat grain extensive, at farm/CH U	1	1		1	1	1	1	1	1	1			1	1	1		1	1

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
wheat extensive																	1	1
Wheat grains IP, at farm/CH S - Wheat grains IP, at farm/CH U	1	1		1	1	1	1	1	1	1			1	1	1		1	1
wheat IP																	1	1
Wheat grains organic, at farm/CH S – Wheat grains organic, at farm/CH U	1	1		1	1	1	1	1	1	1			1	1	1		1	1
wheat organic																	1	1

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Wheat grains, at farm/US S - Wheat grains, at farm/US U	1	1		1	1	1	1	1	1	1		1	1		1		1	1
Wheat grains, at field /kg/US	1						1	1		1	1	1	1				1	
wheat, at field																	1	
Wheat conventional, from farm																		
Winter wheat; at harvest in (year); at farm; 86-90% moisture (state)	1	1				1	1	1	1	1			1				1	1

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Spring wheat; exclu. Durum; at harvest in (year); at farm; 86-90% moisture (state)	1	1				1	1	1	1	1			1				1	1
Durum wheat; at harvest in (year); at farm; 88-89% moisture (state)	1	1				1	1	1	1	1			1				1	1
Wheat, organic, From farm																		
Environmental burdens of producing bread wheat, oilseed rape, and potatoes in England and Wales using simulation and system modeling			1					1	1	1		1	1	1		1	1	

Table 24 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
The impact of local crops consumption on the water resources in Beijing												1						
System delimitation in agricultural consequential LCA: outline of methodology and illustrative case study of wheat in Denmark																	1	

Table 25 – Processed Agricultural Data Summary

Name	Data Availability	Allocation*	Details	Includes	Data Years	Data Country
Bagasse, from Sugarcane, at Sugar refinery/BR/ S - Bagasse, from Sugarcane, at Sugar refinery/BR/ U	Ecoinvent	100.0%	Inventory refers to the production of 1 kg sugar, respectively 1 kg ethanol (95%w/w dry basis, i.e. 1.05kg hydrated ethanol 95% wet basis). 1 kg excess bagasse, I kWh electricity and 1 kg vinasse.	transport of sugarcane to the sugar refinery and the processing of the sugarcane to sugar, ethanol, bagasse, excess electricity and vinasse from ethanol production. System boundary is at the sugar refinery. Treatment of waste effluents is not included. Packaging is not included.	2004-2005	Brazil
bagasse, from sweet sorghum, at distillery	Ecoinvent					China

Table 25 (cont'd)

corn stover, at conversion plant, 2022	USLCI		"This process transports corn stover to the conversion plant. It does so using transportation modal allocation from the USDA Ethanol Backgrounder (2007), assuming those current allocations are applicable to stover and for year 2022. Distances for each mode are from a combination of references; still missing a good distance estimate for barge, but since the share of barge transportation is ~2%, the final result will not be sensititive to this parameter."(USLCI).	Infrastructure impacts are included in this process by calling the Ecoinvent "transport" processes. The production of corn stover feedstock utilized in this transport process assigns inputs to corn stover based on activities and inputs that are required for the growth and harvest and preprocessing of corn stover and none of the activities or inputs that would normally be used to produce, harvest and preprocess corn grain (so-called "incremental allocation").(USLCI).	2022	USA
corn stover, carted	USLCI		Further processing of corn stover production average 2022	Bailing, transport	2022	USA

Table 25 (cont'd)

corn stover, ground and stored	USLCI		"Taken from Sheehan, Corn Stover Ethanol LCA. (Directly from TEAM). The corn steep liquor production involves the steeping of harvested corn for a period of from 24 to 48 hours in a light sulfurous acid solution. All of the production burdens from corn are assumed to be allocated to the production of the SOx." (USLCI).	Direct emissions Sox, machinery, storage, loading, drying (electricity), grinding		USA
Corn stover, production, average, US, 2022	USLCI		"Corn stover based on US average corn yeilds and practices extrapolated from historic data to 2022. Grain and components are assumed to be at field-dry conditions of 15.5% moisture. The stover process has been seperated from corn to allow for incremental allocation. Only processes directly attributed to stover collection are counted."(USLCI).	"These processes include additional harvesting energy for single pass harvest, additional nutrients, and hay substitition for loss of potential over-winter cattle feed."(USLCI).		USA

Table 25 (cont'd)

Pulps, from sugar beet, at sugar refinery/CH S - Pulps, from sugar beet, at sugar refinery/CH U	Ecoinvent	3.8%	1 kg sugar, 1 kg molasses andd 1 kg of pulps. Economic allocation with allocation factor for common stages of 91.7% to sugar, 4.5% to molasses, and 3.8% to pulps. Allocation is done according to carbon balance for CO2 emissions.	Transport of sugar beets to the sugar refinery, and the processing of sugar beets to sugar, molasses and pulps. System boundary is at the sugar refinery. Treatment of waste effluents is included. Packaging of sugar is not included.	1998-2005	Switzerland
Palm kernel meal, at oil mill/MY S - Palm kernel meal, at oil mill/MY U	Ecoinvent	1.4%	1 kg palm kernel meal, from palm fruit bunches. 1.4% allocated to meal. CO2 emissions allocated based on carbon balance.	extraction of palm kernel meal, energy supply from extracted solids, and treatment of specific wastwater effluents are taken into account. System boundary is at the oil mill. (Sterilization, stripping, digestion, oil extraction, screening, settling and refining).	1995-2006	Malaysia
Rape meal, at oil mill/CH S - Rape meal, at oil mill/CH U	Ecoinvent	25.7%	1 kg rape meal, economic allocation of 25.7% to meal. CO2 emissions allocation based on carbon balance.	Transport of rape seeds to the mill, and the processing of the seeds to rape oil and rape meal. Cold press oil extraction technique. System boundary at oil mill.	1998-2006	Switzerland

Table 25 (cont'd)

Rape meal, at oil mill/RER S - Rape meal, at oil mill/RER U	Ecoinvent	25.7%	1 kg rape meal, economic allocation of 25.7% to meal. CO2 emissions allocation based on carbon balance.	Transport of rape seeds to the mill, and the processing of the seeds to rape oil and rape meal. Cold press oil extraction technique. System boundary at oil mill.	1996-2003	Europe
Soybean meal, at oil mill/BR S - Soybean meal, at oil mill/BR U	Ecoinvent	59.3%	1 kg soybean meal (incl. hulls). Economic allocation of 59.3% to meal. CO2 allocated based on carbon balance.	Transport of soybean to the mill, processing of soybeans into meal and oil by the solvent method (pre-cracking, de-hulling, oil extraction, meal processing and oil purification).	1998-2005	Brazil
LCA of soybean meal	Ecoinvent		Fuctional unit is 1 kg of soybean meal produced in argentina and delivered to the netherlands. Global warming, ozone depletion acidification, eurtrophication and photochemical oxidation reported. Two scenarios reported for allocation: economic and mass.	fertilizer, diesel, electric, transport, credit for avoided products	2008	Argentina / Netherlands

Table 25 (cont'd)

wheat straw, at conversion plant, 2022	USLCI		"This process transports wheat straw to the conversion plant. It does so using transportation modal allocation from the USDA Ethanol Backgrounder (2007), assuming the current corn grain allocations described in the report are applicable to wheat straw and to year 2022. Distances for each mode are from a combination of references; still missing a good distance estimate for barge, but since the share of barge transportation is ~2%, the final result will not be sensitive to this parameter." (USLCI).		2022	North America
Soybean meal, at oil mill/US S - Soybean meal, at oil mill/US U	Ecoinvent	65.5%	1 kg soybean meal (incl. hulls). Economic allocation of 65.5% to meal. CO_2 allocated based on carbon balance.	transport of soybean to the mill, processing of soybeans into meal and oil by the solvent method (pre-cracking, dehulling, oil extraction, meal processing and oil purification).	1998-2005	USA

Table 25 (cont'd)

Life cycle assessment of hydrotreated vegetable oil from rape, palm oil, and Jatropha	Journal of cleaner production vol 19 Iss 2-3		Cradle to grave study. Includes from the production of the vegetable oil to its combustion. Process contribution for each stage is available. Reports: fossil fuels, GWP, acidification, and eutrophication. Data for Rape, palm oil, and Jatropha	Crop production, oil extraction, combustion.	2011	Germany, India, Malaysia
Vegetable oil, from cooking oil, at plant/CH S - Vegetable oil, from cooking oil, at plant/CH U	Ecoinvent		Treated vegetable oil consists of 93.7% triglycerides and 6.7% fatty acid methyl ester. Process refers to the acid-catalyzed esterification of free fatty acids and includes water removal, glycerin washing and methanol recovery.	Collection of waste vegetable oil and deliver to the treatment plant, treatment for impurities and water removal, conditioning and storage of the oil. Treatment of effluents is taken into account. Includes gross calorific value of the biomass and the carbon dioxide credit. System boundary is at the oil refining facility.		China

Table 25 (cont'd)

Vegetable oil, from cooking oil, at plant/FR S - Vegetable oil, from cooking oil, at plant/FR U	Ecoinvent		Treated vegetable oil consists of 93.7% triglycerides and 6.7% fatty acid methyl ester. Process refers to the acid-catalyzed esterification of free fatty acids and includes water removal, glycerin washing and methanol recovery. C57H102O6. Data is mostly from one US literature sources and adapted to FR.	Collection of waste vegetable oil and deliver to the treatment plant, treatment for impurities and water removal, conditioning and storage of the oil. Treatment of effluents is taken into account. Includes gross calorific value of the biomass and the carbon dioxide credit. System boundary is at the oil refining facility.		France
Tallow, at plant/CH S - Tallow, at plant/CH U	Ecoinvent	100.00%	1 kg tallow at rending plant. Since the processes of making tallow and meat and bone meal are very similar, this process may also be used to approximate the production of meat and bone meal.	includes transport from slaughterhouse to rendering plant and further processing of slaughterhouse wastes to tallow. Energy demand for operation a rending plant (electricity and natural gas, use of tap water, output of waste water and building infrastructure) is included. Upstream processes not included as tallow material is considered as waste.		Switzerland

Table 25 (cont'd)

Crude coconut oil, at plant/PH S - Crude coconut oil, at plant/PH U	Ecoinvent	100.0%	Data based on the ECOSOL study of the European surfactant industry. Allocation based on mass of outputs.	Material and energy input, production of waste and emissions for the steps from the harvested coconuts to the crude coconut oil (Halving, extraction of water, meat removal and shell production, drying and oil extraction). Water consumption and infrastructure are estimated.		Philippines
Crude palm kernel oil, at plant/RNA	USLCI	100.0%				North America
Palm Kernel Oil, at oil mill/MY S - Palm Kernel Oil, at oil mill/MY U	Ecoinvent	17.3%	Production of 1 kg palm kernel oil. 17.3% allocated to palm kernel oil. CO2 emissions based on carbon balance	Extracting of palm kernel oil from palm fruit bunches, energy supply from extracted solids, treatment of specific wastewater effluents are included. System boundary is at the oil mill.	1995-2006	Malaysia
Palm kernel oil, processed, at plant/RNA	USLCI	100.0%	Palm kernel oil, processed, at plant. Physical refining using steam distillation in high temperature vacuum.			North America

Table 25 (cont'd)

Palm kernels, at plant	USLCI		"Bunch ash, crude palm oil, and shells used in road construction have been treated as coproducts, for which credit has been given on a mass basis. Mass imbalance is due to unavailability of the weight of empty fruit bunches sent to incineration" (USLCI).	Waste, harvesting, transport, incineration of waste wood.		Malaysia
Palm oil, at oil mill/MY S - Palm oil, at oil mill/MY U	Ecoinvent	81.3%	Production of 1 kg palm l oil. 81.3% allocated to palm oil. CO2 emissions based on carbon balance	Extracting of palm oil from palm fruit bunches, energy supply from extracted solids, treatment of specific wastewater effluents are included. System boundary is at the oil mill.	1995-2006	Malaysia
Comparative LCA of rapeseed oil and palm oil	International Journal of LCA February 2010		Consequential LCA that used system expansion to avoid allocation. Rapeseed data is for Denmark, Palm oil data is from Malaysia and Indonesia	cultivation, oil milling, refining		Denmark, Malaysia, Indonesia

Table 25 (cont'd)

Rape oil, at oil mill/CH S - Rape oil, at oil mill/CH U	Ecoinvent	74.3%	1 kg rape oil. Allocation is economic with 74.3% to rape oil. CO2 is allocated based on carbon balance.	Transport of seeds to mill, processing of seeds to rape oil and rape meal. The oil extraction refers to the cold-press extraction method. System boundary at oil mill.	1998-2006	Switzerland
Rape oil, at oil mill/RER S - Rape oil, at oil mill/RER U	Ecoinvent	74.3%	1 kg rape oil. Allocation is economic with 74.3% to rape oil. CO2 is allocated based on carbon balance.	Transport of seeds to mill, processing of seeds to rape oil and rape meal. The oil extraction refers to the solvent extraction method. System boundary at oil mill.	1996-2003	Europe
Rape oil, at regional storage/CH S - Rape oil, at regional storage/CH U	Ecoinvent	100.0%	Distribution of 1 kg rape oil in Switzerland	Transport of rape oil from the oil mill to the end user, including operation of storage tanks and equipment. Emissions from evaporation and treatment of effluents.		Switzerland

Table 25 (cont'd)

Soya oil, at plant/RER S - Soya oil, at plant/RER U	Ecoinvent	28.0%	Manufacturing process starting with dry beans. 28% allocation to Soya Oil.	The inventory includes the conditioning (but not drying) of the beans before extraction. The production of soya scrap is also included as well as the consumption of auxiliaries, energy, infrastructure and land use, generation of emissions to land and water. Generation and transportation of solid waste is not included.		Europe
Soybean oil, at oil mill/BR S - Soybean oil, at oil mill/BR U	Ecoinvent	40.7%	1 kg soybean oil, system boundary at oil mill. Economic allocation of 40.7% to oil. CO2 allocated based on carbon balance.	Transport of soybeans to the mill, processing in to soybean oil. Solvent extraction process (Pre-cracking of beans, de-hulling, oil extraction, meal processing and oil purification).		Brazil
Soy oil, refined, at plant	USLCI		"Energy data: late 2000s, other data: theoretical. CARBON SEQUESTRATION should be accounted for after the product is built in its LCA model, and should be included depending on the use of end of life fate of that product" (USLCI).	Waste disposal, process energy, transport, materials		USA

Table 25 (cont'd)

Soybean oil, crude, degummed, at plant	USLCI		"CARBON SEQUESTRATION should be accounted for after the product is built in its LCA model, and should be included depending on the use of end of life fate of that product. For example, a soy-based resin may retain the sequestered carbon indefinitely, while a soy-based biodiesel releases the sequestered carbon at use phase." (USLCI).	Materials, transportation, water, waste disposal, natural gas, electricity		North America
Soybean oil, at oil mill/US S - Soybean oil, at oil mill/US U	Ecoinvent	34.5%	1 kg soybean oil, system boundary at oil mill. Economic allocation of 34.5% to oil. CO2 allocated based on carbon balance.	Transport of soybeans to the mill, processing in to soybean oil. Solvent extraction process (Pre-cracking of beans, de-hulling, oil extraction, meal processing and oil purification).		USA
Determination of GHG contributions by subsystems in the oil palm supply chain using the LCA approach	International Journal of Life Cycle Assessment August 2011		Primary data collected from 12 palm nurseries, 102 plantations, 12 mills and 11 refineries.	Cultivation of seedlings, cultivation of palms, land use, milling, refining, Trans esterification, and utilization of diesel in engines of vehicles	2011	Malaysia

Table 25 (cont'd)

An eco-profile of thermoplastic protein derived from blood meal	International Journal of Life Cycle Assessment - Bier et all.		LCA data for making NTP (Novatein Thermoplastic Protein) from blood meal. Only non-renewable energy and GHG emissions are reported. NTP has applications similar to LLDPE. New Zealand has higher than average wind energy use, other locations would have more non-renewable energy reported.	Farming processes: raising cattle, fuel and electric for farm activities, nitrogen and phosphate fertilizer for cattle feed. Meat Processing: slaughtering, blood collection, removing of offal, cutting of meat, rendering, steam coagulation, drying blood, milling into blood meal. Other processes included in Part 2 of the paper.	2011	New Zealand
Whey, at dairy/CH S - Whey, at dairy/CH U	Ecoinvent	100.00%	Process is only a credit entry accounting for the extraction of CO_2 from the atmosphere. 4.9% lactose, 0.5% lipids	Credit for removed CO_2		Switzerland

Table 25 (cont'd)

corn grain, at conversion plant, 2022	USLCI		This process transports corn grain to the conversion plant. It does so using transportation modal allocation from the USDA Ethanol Backgrounder (2007), assuming this current allocation will apply in 2022. Distances for each mode are from a combination of references; still missing a good distance estimate for barge, but since the share of barge transportation is ~2%, the final result will not be sensitive to this parameter.	Infrastructure impacts are included in this process by calling the Ecoinvent "transport" processes. The production of corn grain feedstock utilized in this transport process allocates inputs to the stover and grain based on the amount of ethanol that can be produced from each co-product	2022	USA
an environmental life cycle assessment comparing Australian sugarcane with US corn and UK sugar beet as producers of sugar for Fermentation	Biomass and Bioenergy Vol 32 (2008)		Functional unit is 1 kg of glucose or fructose for fermentation. The three things that were found to have the greatest effect on environmental performance were: commodities displaced by bio-products, agricultural yields, and nitrogen use efficiency.	Fertilizer, lime, pesticide, water for irrigation, harvesting, milling, bagasse combustion (for sugarcane only), electricity, transport, machinery, fuel use, clarification.	2008	USA, UK, and Australia

Table 25 (cont'd)

corn grain, harvested and stored	USLCI		Further processing of corn grain for 2022	Ventilated storage, transport, loading, conveyor belt	2022	USA
Maize starch, at plant/DE S - Maize starch, at plant/DE U	Ecoinvent	100.0%				Germany
Potato starch, at plant/DE S - Potato starch, at plant/DE U	Ecoinvent	100.0%		Washing of potatoes, chopping, separation of potato fruit water, second washing, refining, starch drying. Process water included, infrastructure use considered.		Germany
Potato starch / potato flour	LCA Food DK					Denmark
Molasses, from sugar beet, at sugar refinery/CH S - Molasses, from sugar beet, at sugar refinery/CH U	Ecoinvent	4.5%	1 kg sugar, 1 kg molasses and 1 kg of pulps. Economic allocation with allocation factor for common stages of 91.7% to sugar, 4.5% to molasses, and 3.8% to pulps. Allocation is done according to carbon balance for CO2 emissions.	Transport of sugar beets to the sugar refinery, and the processing of sugar beets to sugar, molasses and pulps. System boundary is at the sugar refinery. Treatment of waste effluents is included. Packaging of sugar is not included.		Switzerland

Table 25 (cont'd)

an environmental life cycle assessment comparing Australian sugarcane with US corn and UK sugar beet as producers of sugar for Fermentation	Biomass and Bioenergy Vol 32 (2008)		Functional unit is 1 kg of glucose or fructose for fermentation. The three things that were found to have the greatest effect on environmental performance were: commodities displaced by bio-products, agricultural yields, and nitrogen use efficiency.	Fertilizer, lime, pesticide, water for irrigation, harvesting, milling, bagasse combustion (for sugarcane only), electricity, transport, machinery, fuel use, clarification.	2008	USA, UK, and Australia
Carbon footprint of sugar produced from sugarcane in eastern Thailand	Journal of cleaner production vol 19		Reports estimated GHG emissions from CO2, CH4, and N2O.	Tilling, irrigation, herbicide and pesticide application, diesel, fertilizer, biomass burning, transport, energy use and waste water treatment.	2011	Thailand
Sugarcane as a Carbon Source: The Brazilian Case	Journal of Biomass and Bioenergy					Brazil

Table 25 (cont'd)

sugarcane, in sugar refinery	GaBi PE		The multi-output process "sugarcane, in sugar refinery" delivers the co-products: Sugar, ethanol 95% in H2O, sugarcane molasses, bagasse, electricity, and vinasse. Economic allocation with 80-85% to sugar and 10-11% to ethanol. Allocation according to carbon balance for CO2.				
Life cycle assessment of Australian sugar cane with a focus on cane processing	International Journal of Lice Cycle Assessment Sept 2010						Australia

Table 25 (cont'd)

an environmental life cycle assessment comparing Australian sugarcane with US corn and UK sugar beet as producers of sugar for Fermentation	Biomass and Bioenergy Vol 32 (2008)		Functional unit is 1 kg of glucose or fructose for fermentation. The three things that were found to have the greatest effect on environmental performance were: commodities displaced by bio-products, agricultural yields, and nitrogen use efficiency.	Fertilizer, lime, pesticide, water for irrigation, harvesting, milling, bagasse combustion (for sugarcane only), electricity, transport, machinery, fuel use, clarification.	2008	USA, UK, and Australia
switchgrass, carted, 2022	USLCI		Crop Production - unspecified			

Table 25 (cont'd)

Switchgrass, at conversion plant, 2022	USLCI		This process transports switchgrass to the conversion plant using transportation modal allocation from the USDA Ethanol Background (2007), assuming these current corn grain allocations are applicable to switchgrass and to year 2022. Distances are from a combination of references; still missing a good distance estimate for barge, but since the share of barge transportation is ~2%, the final result will not be sensitive to this parameter.	Infrastructure impacts are included in this process by calling the Ecoinvent "transport" processes.	2022	USA
Switchgrass, ground and stored, 2022	USLCI				2022	USA

Table 25 (cont'd)

Combinational Life Cycle Assessment to inform Process Design of Industrial Production of Algal Biodiesel	Environmental Science and Technology 2011		All stages of production are considered separately and multiple methods are included for each process.	Algae cultivation, harvesting, de-watering, lipid extraction, conversion into bio-diesel, by-product management.	2011	General
Harvesting microalgal biomass using submerged microfiltration membranes	Bioresource Technology volume 111 May 2012		This was a lab scale study and only energy consumption was reported, includes cleaning of the filters. Study compares filters with different pore sizes.		2012	General
Preferential technological and lice cycle environmental performance of chitosan flocculation for harvesting of the green algae Neochloris oleoabundans	Biosource Technology 2012		This article includes LCA data for the harvesting and processing of algae. It uses the TRACI model of impacts.	Algae harvesting, harvesting of Chitin and processing into Chitosan, Al and Fe extraction and processing, machine manufacturing and operation, treatment of wastewater and solid waste. All energy and materials inputs are included, but cultivation of algae is not.	2012	General
*Allocation based on economic value unless noted otherwise						

Table 26 - Processed Agricultural Data Summary Inputs

Name	Loading	Land Use	Material	Transport	Waste Treatment	Infrastructure	Machines	Process Energy	De-Hulling	Digestion	Stripping	Extraction	Screening	Refining	Water	Drying	Direct Emissions	Harvesting
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Bagasse, from Sugarcane, at Sugar refinery/BR/ S - Bagasse, from Sugarcane, at Sugar refinery/BR/ U				1				1										
bagasse, from sweet sorghum, at distillery																		
corn stover, at conversion plant, 2022				1														
corn stover, carted			1	1			1	1										

Table 26 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
corn stover, ground and stored	1						1	1		1						1	1	
Corn stover, production, average, US, 2022			1			1	1											
Pulps, from sugar beet, at sugar refinery/CH S - Pulps, from sugar beet, at sugar refinery/CH U				1	1			1										
Palm kernel meal, at oil mill/MY S - Palm kernel meal, at oil mill/MY U					1			1		1	1	1	1	1				

Table 26 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Rape meal, at oil mill/CH S - Rape meal, at oil mill/CH U				1				1				1						
Rape meal, at oil mill/RER S - Rape meal, at oil mill/RER U				1				1				1						
Soybean meal, at oil mill/BR S - Soybean meal, at oil mill/BR U				1					1			1						
LCA of soybean meal			1					1										
wheat straw, at conversion plant, 2022																		
Soybean meal, at oil mill/US S - Soybean meal, at oil mill/US U				1				1	1			1		1				

Table 26 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Life cycle assessment of hydrotreated vegetable oil from rape, palm oil, and Jatropha			1					1										
Vegetable oil, from cooking oil, at plant/CH S - Vegetable oil, from cooking oil, at plant/CH U				1	1			1								1		
Vegetable oil, from cooking oil, at plant/FR S - Vegetable oil, from cooking oil, at plant/FR U				1	1			1								1		
Tallow, at plant/CH S - Tallow, at plant/CH U				1	1	1		1							1			

Table 26 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Crude coconut oil, at plant/PH S - Crude coconut oil, at plant/PH U			1		1	1		1							1	1		
Crude palm kernel oil, at plant/RNA																		
Palm Kernel Oil, at oil mill/MY S - Palm Kernel Oil, at oil mill/MY U					1			1				1						
Palm kernel oil, processed, at plant/RNA																		
Palm kernels, at plant			1	1	1													1
Palm oil, at oil mill/MY S - Palm oil, at oil mill/MY U					1			1				1						

Table 26 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Comparative LCA of rapeseed oil and palm oil																		
Rape oil, at oil mill/CH S - Rape oil, at oil mill/CH U				1				1				1						
Rape oil, at oil mill/RER S - Rape oil, at oil mill/RER U				1				1				1						
Rape oil, at regional storage/CH S - Rape oil, at regional storage/CH U					1		1										1	
Soya oil, at plant/RER S - Soya oil, at plant/RER U		1				1		1	1								1	
Soybean oil, at oil mill/BR S - Soybean oil, at oil mill/BR U		1						1	1			1		1				

Table 26 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Soy oil, refined, at plant			1	1	1			1										
Soybean oil, crude, degummed, at plant			1	1	1			1							1			
Soybean oil, at oil mill/US S - Soybean oil, at oil mill/US U		1						1	1			1		1				
Determination of GHG contributions by subsystems in the oil palm supply chain using the LCA approach		1	1									1		1				1
An eco-profile of thermoplastic protein derived from blood meal		1	1					1								1		

Table 26 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Whey, at dairy/CH S - Whey, at dairy/CH U																		
corn grain, at conversion plant, 2022																		
an environmental life cycle assessment comparing Australian sugarcane with US corn and UK sugar beet as producers of sugar for Fermentation			1	1			1	1				1		1	1			1
corn grain, harvested and stored			1	1			1	1										
Maize starch, at plant/DE S - Maize starch, at plant/DE U																		

Table 26 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Potato starch, at plant/DE S - Potato starch, at plant/DE U																		
Potato starch / potato flour																		
Molasses, from sugar beet, at sugar refinery/CH S - Molasses, from sugar beet, at sugar refinery/CH U		1			1			1										
an environmental life cycle assessment comparing Australian sugarcane with US corn and UK sugar beet as producers of sugar for Fermentation			1	1			1	1				1		1	1			1

Table 26 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Carbon footprint of sugar produced from sugarcane in eastern Thailand			1	1	1			1									1	1
Sugarcane as a Carbon Source: The Brazilian Case																		
sugarcane, in sugar refinery														1	1			
Life cycle assessment of Australian sugar cane with a focus on cane processing																		

Table 26 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
an environmental life cycle assessment comparing Australian sugarcane with US corn and UK sugar beet as producers of sugar for Fermentation			1	1			1	1				1		1	1			1
switchgrass, carted, 2022																		
Switchgrass, at conversion plant, 2022																		
Switchgrass, ground and stored, 2022																		
Combinational Life Cycle Assessment to inform Process Design of Industrial Production of Algal Biodiesel		1	1		1			1		1						1		1

Table 26 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Harvesting microalgal biomass using submerged microfiltration membranes																		
Preferential technological and lice cycle environmental performance of chitosan flocculation for harvesting of the green algae Neochloris Oleoabundans			1		1		1	1							1			1

Table 27 – Wood Data Summary

Name	Data Availability	Allocation*	Details	Includes	Data Years	Data Country
Waste paper, mixed, from public collection, for further treatment/CH S - Waste paper, mixed, from public collection, for further treatment/CH U	Ecoinvent	100.0%	Collected waste paper has a biogenic C content of 40.4 % (Average 2004)	Transportation for the collection as well as the further transportation to the next paper production site. Nothing else included.		Switzerland
Waste paper, mixed, from public collection, for further treatment/RER S - Waste paper, mixed, from public collection, for further treatment/RER U	Ecoinvent	100.0%	Collected waste paper has a biogenic C content of 40.4 % (Average 2004)	Transportation for the collection as well as the further transportation to the next paper production site. Nothing else included.		Europe

Table 27 (cont'd)

Waste paper, sorted, for further treatment/CH S - Waste paper, sorted, for further treatment/CH U	Ecoinvent	100.0%	Collected waste paper	Includes sorting of collected paper (energy and materials), treatment of extracted wastes, and transportation to the next paper production site. Nothing else included.		Switzerland
Waste paper, sorted, for further treatment/RER S - Waste paper, sorted, for further treatment/RER U	Ecoinvent	100.0%	Collected waste paper	Includes sorting of collected paper (energy and materials), treatment of extracted wastes, and transportation to the next paper production site. Nothing else included.		Europe
Forest residue, processed and loaded, at landing system	USLCI					USA
Bark, softwood, average, state or private moist cold forest, at forest road, INW	USLCI				1989-1996	US Inland West

Table 27 (cont'd)

Bark chips, softwood, u=140%, at forest road/RER S - Bark chips, softwood, u=140%, at forest road/RER U	Ecoinvent	100.0%	Tractor driven debarking delivers the two coproducts "round wood, softwood, debarked, u=70% at forest road" and "bark chips, softwood, u=140%, at forest road". Allocation based on the overall proceeds of the process. Data for Germany used for central Europe.			Germany / Central Europe
Bark chips, softwood, u=140%, at plant/RER S - Bark chips, softwood, u=140%, at plant/RER U	Ecoinvent	100.0%	Volume refers to the wood not including the bark. Allocation is based on economic value.	transports from forest, sawing, and debarking at sawmill		Germany / Central Europe
Bark mulch, at oriented strand board production, US SE/kg/US	USLCI	3.3%				US South East

Table 27 (cont'd)

Bark, at sawmill, US SE/kg/US	USLCI	13.0%	Debarking of logs, sawing and sorting of green lumber			US South East
Bark, at plywood plant, US PNW/kg/US	USLCI	5.6%	Log debarking at plant yielding wood and bark, bark used to fire boiler.			US Pacific North West
Bark, at plywood plant, US SE/kg/US	USLCI	6.3%	Log debarking at plant yielding wood and bark, bark used to fire boiler.			US South East
Bark, at rough green lumber sawmill, softwood, US PNW/kg/US	USLCI	7.7%	Debarking of logs, sawing and sorting of green lumber			US Pacific North West

Table 27 (cont'd)

Chips, Scandinavian softwood (plant-debarked, u=70%, at plant/NORDEL S - Chips, Scandinavian softwood (plant-debarked, u=70%, at plant/NORDEL U	Ecoinvent	100.0%	Allocation based on economic criteria.	Debarking and further production of sawn timber, wood chips and sawdust. Transport of wood from forest road to sawmill is included.		Sweden and Finland
Co-products of glue laminated beam production, at plant, unspecified, US PNW/kg/US	USLCI	18.3%	Allocation based on mass or volume	Final manufacture of 1000cuft of Glulam beams from dry and rough green lumber (and coproducts)		US Pacific North West
Co-products of glue laminated beam production, at plant, unspecified, US SE/kg/US	USLCI	17.6%	Allocation based on mass or volume	Final manufacture of 1000cuft of Glulam beams from dry and rough green lumber (and coproducts)		US South East
Co-products of laminated veneer lumber production, unspecified, US PNW/kg/US	USLCI	4.4%	Allocation based on mass or volume	Final manufacture of 1000cuft of LVL from plywood and dry veneer (and coproducts)		US Pacific North West

Table 27 (cont'd)

Co-products of laminated veneer lumber production, unspecified, US SE/kg/US	USLCI	8.7%	Allocation based on mass or volume	Final manufacture of 1000cuft of LVL from plywood and dry veneer (and coproducts)		US South East
Dust and scrap, at oriented strand board production, US SE/kg/US	USLCI	0.7%	Gate to gate system analysis. Allocation based on mass or volume			US South East
Fines, at oriented strand board production, US SE/kg/US	USLCI	1.4%	Gate to gate system analysis. Allocation based on mass or volume			US South East
Hogfuel, from trim and saw at plywood plant, US PNW/kg/US	USLCI	11.6%	Trim and saw process, at plywood plant. Allocation based on mass or volume.			US Pacific North West
Hogfuel, from trimsaw, plywood plant, US SE/kg/US	USLCI	4.4%	Trim and saw process, at plywood plant. Allocation based on mass or volume.			US South East

Table 27 (cont'd)

Panel trim, from trim and saw at plywood plant, US PNW/kg/US	USLCI	9.0%	Final trim and saw to length of plywood. Allocation based on mass or volume.			US Pacific North West
Panel trim, from trim and saw at plywood plant, US SE/kg/US	USLCI	5.2%	Final trim and saw to length of plywood. Allocation based on mass or volume.			US South East
Peeler core, from green veneer production at plywood plant, US PNW/kg/US	USLCI	5.3%	Rotary peeling of logs to produce green veneer. Allocation performed using mass or volume.			US Pacific North West
Peeler core, from green veneer production at plywood plant, US SE/kg/US	USLCI	7.5%	Rotary peeling of logs to produce green veneer. Allocation performed using mass or volume.			US South East

Table 27 (cont'd)

Planer shavings, at planer mill, US SE/kg/US	USLCI	13.1%	Allocation based on mass or volume	Planed dried lumber processing, at planer mill. Transfer, de-sticking of KD lumber, planing, sorting and stacking.		US South East
Planer shavings, from dried lumber, at planer mill, US PNW/kg/US	USLCI	7.0%	Allocation based on mass or volume.	Planed dried lumber processing, at planer mill. Transfer, de-sticking of KD lumber, planing, sorting and stacking.		US Pacific North West
Planer shavings, from green lumber, at planer mill, US PNW/kg/US	USLCI	7.0%	Allocation based on mass or volume.	Planed green lumber processing, at planer mill. Transfer, de-sticking of KD lumber, planing, sorting and stacking.		US Pacific North West
Pulp chips, at rough green lumber production, US PNW/kg/US	USLCI	26.8%	Allocation based on mass or volume.	Rough green lumber processing, at sawmill. Debarking of logs, sawing and sorting of green lumber.		US Pacific North West

Table 27 (cont'd)

Pulp chips, at sawmill, US SE/kg/US	USLCI	31.5%	Allocation based on mass or volume.	Rough green lumber processing, at sawmill. Debarking of logs, sawing and sorting of green lumber.		US South East
Pulp chips, from dried lumber, at planer mill, US PNW/kg/US	USLCI	6.0%	Allocation based on mass or volume.	Planed dried lumber processing, at planer mill. Transfer, de-sticking of KD lumber, planing, sorting and stacking.		US Pacific North West
Pulp chips, from green lumber, at planer mill, US PNW/kg/US	USLCI	6.0%	Allocation based on mass or volume.	Planed green lumber processing, at planer mill. Transfer, de-sticking of KD lumber, planing, sorting and stacking.		US Pacific North West
Pulp chips, from green veneer production at plywood plant, US PNW/kg/US	USLCI	23.8%	Allocation based on mass or volume.	Rotary peeling of logs to produce green veneer.		US Pacific North West

Table 27 (cont'd)

Pulp chips, from green veneer production at plywood plant, US SE/kg/US	USLCI	56.1%	Allocation based on mass or volume.	Rotary peeling of logs to produce green veneer.		US South East
Sawdust from I-Joist processing, at plant, US SE/kg/US	USLCI	7.0%	Allocation based on mass or volume.	Final manufacture of 100 linear feet of generic I-joists from LVL and OSB inputs		US South East
Sawdust, at planer mill,US SE/kg/US	USLCI	1.9%	Allocation based on mass or volume.	Planed dried lumber processing, at planer mill. Transfer, de-sticking of KD lumber, planing, sorting and stacking.		US South East
Sawdust, at rough green lumber production, us PNW/kg/US	USLCI	8.6%	Allocation based on mass or volume.	Rough green lumber processing, at sawmill. Debarking of logs, sawing and sorting of green lumber.		US Pacific NorthWest
Sawdust, at sawmill, US SE/kg/US	USLCI	5.9%	Allocation based on mass or volume.	Rough green lumber processing, at sawmill. Debarking of logs, sawing and sorting of green lumber.		US South East

Table 27 (cont'd)

Sawdust, from dried lumber, at planer mill, US PNW/kg/US	USLCI	1.0%	Processing of 1000 board feet of surfaced, kiln dried softwood lumber. Allocation based on mass or volume.	Planed dried lumber processing, at planer mill. Transfer, de-sticking of KD lumber, planing, sorting and stacking.		US Pacific North West
Sawdust, from green lumber, at planer mill, US PNW/kg/US	USLCI	1.0%	Processing of 1000 board feet of surfaced, green softwood lumber. Allocation based on mass or volume.	Planed green lumber processing, at planer mill. Transfer, planing, sorting and stacking.		US Pacific North West
Sawdust, from I-Joist processing, at plant, US PNW/kg/US	USLCI	10.2%	Allocation based on mass or volume.	Final manufacture of 100 linear feet of generic I-joists from LVL and OSB inputs		US Pacific North West

Table 27 (cont'd)

Sawdust, from trim and saw at plywood plant, US PNW/kg/US	USLCI	0.8%	Allocation based on mass or volume.	Final trim and saw to length of plywood		US Pacific North West
Sawdust, from trim and saw, plywood plant, US SE/kg/US	USLCI	0.4%	Allocation based on mass or volume.	Final trim and saw to length of plywood		US South East
Sawdust, Scandinavian softwood (plant-debarked), u=70%, at plant/NORDEL S - Sawdust, Scandinavian softwood (plant-debarked), u=70%, at plant/NORDEL U	Ecoinvent	100% economic allocation	Economic allocation	Debarking and further production of sawn timber, wood chips and sawdust. Transport of wood from forest road to sawmill is included.		Sweden and Finland

Table 27 (cont'd)

Waste wood chips, mixed, from industry, u=40%, at plant/CH S - Waste wood chips, mixed, from industry, u=40%, at plant/CH U	Ecoinvent	100.0%	28% hard wood, 72% soft wood bulked volume. Density 239-169 kg/m3 dry mass.	Transport of waste urban and demolition wood to the chopping facility (50km), infrastructure, chopping of the wood into chips in sawmill, consumption of water and the disposal of effluents and wastes from sorting. Includes carbon dioxide credit. No specific treatment of the wood is considered.		Austria and Switzerland / Central Europe
Wood chips, hardwood, from industry, u=40%, at plant/RER S - Wood chips, hardwood, from industry, u=40%, at plant/RER U	Ecoinvent	100.0%	Bulked volume dried matter content 239 kg/m3.	Chopping of residual hardwood with a stationary chopper in the sawmill. No transports for the inputs are assumed.		Austria / Central Europe

Table 27 (cont'd)

Wood chips, hardwood, u=80%, at forest/RER S - Wood chips, hardwood, u=80%, at forest/RER U	Ecoinvent	100.0%	Bulked volume dried matter content 239 kg/m3.	Chopping of residual hardwood with a mobile chopping in the forest. Also includes the driving of the mobile chopper to and within the forest.		Austria / Central Europe
Wood chips, mixed, from industry, u=40%, at plant/RER S - Wood chips, mixed, from industry, u=40%, at plant/RER U	Ecoinvent	100.0%	Average mix 72% softwood and 28% hardwood (Swiss average).	Chopping residual wood with stationary chopper in the sawmill. No transports are included.		Austria and Switzerland / Central Europe

Table 27 (cont'd)

Wood chips, mixed, u=120%, at forest/RER S - Wood chips, mixed, u=120%, at forest/RER U	Ecoinvent	100.0%	Average mix 72% softwood and 28% hardwood (Swiss average).	Chopping of residual wood with a mobile chopper in the forest. Also includes the driving of the mobile chopper to and within the forest.		Austria and Switzerland / Central Europe
Wood chips, softwood, from industry, u=40%, at plant/RER S - Wood chips, softwood, from industry, u=40%, at plant/RER U	Ecoinvent	100.0%	Bulked volume dried matter content 169 kg/m3.	Chopping residual softwood with stationary chopper in the sawmill. No transports are included.		Austria / Central Europe

Table 27 (cont'd)

Attributional life cycle assessment of wood chips for bioethanol production	Journal of cleaner Production Vol 19 Iss 8		Functional unit is 4 cubic meters of hardwood chips. Cradle to gate study.	Weed control, tree felling, skidding, seedling production, site preparation and plantation, harvesting and woodchip processing, transport to facility, soil scarification, bucking, de-limbing.		USA (Maine)
Comparative life cycle assessment of ethanol production from fast-growing wood crops (black locust, eucalyptus and poplar)	Journal of Biomass and Bioenergy April 2012		The use of ethanol derived from black locust was found to have the lowest impact in most categories. Global warming potential over 100 years reduced 97%, Acidification potential reduced 42%, Eutrophication potential reduced 41%, Fossil fuels use reduced 76%.		2012 (published)	Italy
Wood chips, softwood, u=140%, at forest/RER S - Wood chips, softwood, u=140%, at forest/RER U	Ecoinvent	100.0%	Bulked volume dried matter content 169 kg/m3.	Chopping of residual softwood with a mobile chopper in the forest. Also includes the driving of the mobile chopper to and within the forest.		Austria / Central Europe

*Allocation is mass based unless indicated otherwise.

Table 28 – Wood Data Summary Inputs

Name	Transport to Process Facility	Transport of Equipment	Debarking	Sawing	Planting	Sorting	Stacking	Handling	Drying	Rotary Peeling	Facility Infrastructure	Water Consumption	Energy	Materials	Waste Treatment
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Waste paper, mixed, from public collection, for further treatment/CH S - Waste paper, mixed, from public collection, for further treatment/CH U	1														

Table 28 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Waste paper, mixed, from public collection, for further treatment/RER S - Waste paper, mixed, from public collection, for further treatment/RER U	1														
Waste paper, sorted, for further treatment/CH S - Waste paper, sorted, for further treatment/CH U													1	1	1
Waste paper, sorted, for further treatment/RER S - Waste paper, sorted, for further treatment/RER U													1	1	1

Table 28 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Forest residue, processed and loaded, at landing system															
Bark, softwood, average, state or private moist cold forest, at forest road, INW															
Bark chips, softwood, u=140%, at forest road/RER S - Bark chips, softwood, u=140%, at forest road/RER U			1					1							
Bark chips, softwood, u=140%, at plant/RER S - Bark chips, softwood, u=140%, at plant/RER U	1		1	1											

Table 28 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Bark mulch, at oriented strand board production, US SE/kg/US															
Bark, at sawmill, US SE/kg/US			1	1		1									
Bark, at plywood plant, US PNW/kg/US			1												
Bark, at plywood plant, US SE/kg/US			1												
Bark, at rough green lumber sawmill, softwood, US PNW/kg/US			1	1		1									

Table 28 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Chips, Scandinavian softwood (plant-debarked, u=70%, at plant/NORDEL S - Chips, Scandinavian softwood (plant-debarked, u=70%, at plant/NORDEL U	1		1	1											
Co-products of glue laminated beam production, at plant, unspecified, US PNW/kg/US															
Co-products of glue laminated beam production, at plant, unspecified, US SE/kg/US															
Co-products of laminated veneer lumber production, unspecified, US PNW/kg/US															

Table 28 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Co-products of laminated veneer lumber production, unspecified, US SE/kg/US															
Dust and scrap, at oriented strand board production, US SE/kg/US															
Fines, at oriented strand board production, US SE/kg/US															
Hogfuel, from trim and saw at plywood plant, US PNW/kg/US				1											
Hogfuel, from trimsaw, plywood plant, US SE/kg/US				1											

Table 28 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Panel trim, from trim and saw at plywood plant, US PNW/kg/US				1											
Panel trim, from trim and saw at plywood plant, US SE/kg/US				1											
Peeler core, from green veneer production at plywood plant, US PNW/kg/US										1					
Peeler core, from green veneer production at plywood plant, US SE/kg/US										1					
Planer shavings, at planer mill, US SE/kg/US					1	1	1	1							

Table 28 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Planer shavings, from dried lumber, at planer mill, US PNW/kg/US					1	1	1	1							
Planer shavings, from green lumber, at planer mill, US PNW/kg/US					1	1	1	1							
Pulp chips, at rough green lumber production, US PNW/kg/US			1	1		1									
Pulp chips, at sawmill, US SE/kg/US			1	1		1									
Pulp chips, from dried lumber, at planer mill, US PNW/kg/US					1	1	1	1							

Table 28 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Pulp chips, from green lumber, at planer mill, US PNW/kg/US					1	1	1	1							
Pulp chips, from green veneer production at plywood plant, US PNW/kg/US										1					
Pulp chips, from green veneer production at plywood plant, US SE/kg/US										1					
Sawdust from I-Joist processing, at plant, US SE/kg/US															
Sawdust, at planer mill, US SE/kg/US			1	1		1									

Table 28 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Sawdust, at rough green lumber production, us PNW/kg/US			1	1		1									
Sawdust, at sawmill, US SE/kg/US			1	1		1									
Sawdust, from dried lumber, at planer mill, US PNW/kg/US					1	1	1	1							
Sawdust, from green lumber, at planer mill, US PNW/kg/US					1	1	1								
Sawdust, from I-Joist processing, at plant, US PNW/kg/US															

Table 28 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Sawdust, from trim and saw at plywood plant, US PNW/kg/US				1											
Sawdust, from trim and saw, plywood plant, US SE/kg/US				1											
Sawdust, Scandinavian softwood (plant-debarked), u=70%, at plant/NORDEL S - Sawdust, Scandinavian softwood (plant-debarked), u=70%, at plant/NORDEL U	1		1	1											

Table 28 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Waste wood chips, mixed, from industry, u=40%, at plant/CH S - Waste wood chips, mixed, from industry, u=40%, at plant/CH U	1			1							1	1			1
Wood chips, hardwood, from industry, u=40%, at plant/RER S - Wood chips, hardwood, from industry, u=40%, at plant/RER U				1											
Wood chips, hardwood, u=80%, at forest/RER S - Wood chips, hardwood, u=80%, at forest/RER U		1		1											

Table 28 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Wood chips, mixed, from industry, u=40%, at plant/RER S - Wood chips, mixed, from industry, u=40%, at plant/RER U				1											
Wood chips, mixed, u=120%, at forest/RER S - Wood chips, mixed, u=120%, at forest/RER U		1		1											
Wood chips, softwood, from industry, u=40%, at plant/RER S - Wood chips, softwood, from industry, u=40%, at plant/RER U				1											

Table 28 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Attributional life cycle assessment of wood chips for bioethanol production	1			1	1		1							1	
Comparative life cycle assessment of ethanol production from fast-growing wood crops (black locust, eucalyptus and poplar)															
Wood chips, softwood, u=140%, at forest/RER S - Wood chips, softwood, u=140%, at forest/RER U		1		1											

Table 29 – Chemical Data Summary

Name	Data Availability	Allocation*	Details	Includes	Data Years	Data Country
Ethanol, denatured, forest residues, thermochemical	USLCI			Materials, waste disposal, electricity, diesel, water		North America
Ethanol, denatured, corn stover, biochemical	USLCI			Materials, waste disposal, electricity, diesel, water		North America
Ethanol, denatured, wheat straw, biochemical	USLCI			Materials, waste disposal, electricity, diesel, water		North America
ethanol, denatured, mixed feedstocks, at conversion facility, 2022	USLCI		Blend of corn, corn stover, forest residues, switchgrass and wheat straw ethanol	Materials	2022	North America
Ethanol, denatured, switchgrass, biochemical	USLCI			Materials, waste disposal, electricity, diesel, water		North America

Table 29 (cont'd)

Ethanol, denatured, corn dry mill	USLCI			Corn dried and stored, milling, gluten drying, waste disposal, fermentation, electricity		North America
Corn, in distillery	GaBi PE	97.6%	Production of 1 kg hydrated ethanol 95% dry basis (1.05kg wet basis). Also delivers co-product "DDGS, from corn, at distillery". Economic allocation w/ factor of 97.6% to ethanol. Allocation according to carbon balance for CO2 emissions.			Unspecified
Ethanol, 95% in H2O, from corn, at distillery/US S - Ethanol, 95% in H2O, from corn, at distillery/US U	Ecoinvent	97.6%	1 kg hydrated ethanol 95% (dry basis, i.e. 1.05 kg hydrated ethanol wet basis). Dry milling technology. Economic allocation 97.6% to ethanol. CO2 emissions are allocated based on carbon balance.	Transport of corn grains to the distillery, processing to hydrated ethanol. System boundary is at the distillery and dehydration is not included.	1990-2006	USA

Table 29 (cont'd)

Ethanol, 95% in H2O, from grass, at fermentation plant/CH S - Ethanol, 95% in H2O, from grass, at fermentation plant/CH U	Ecoinvent		Multi-output process "grass, to fermentation" delivers the co-products Ethanol 95%, fibers from grass, and proteins from grass. Economic allocation. Data from a Swiss pilot plant.	Fermentation of grass including materials, energy uses, infrastructure, and emissions.	Time of publications	Switzerland
Ethanol, 95% in H2O, from potatoes, at distillery/CH S - Ethanol, 95% in H2O, from potatoes, at distillery/CH U	Ecoinvent	95.6%	1 kg hydrated ethanol 95% (dry basis, i.e. 1.05 kg hydrated ethanol wet basis). Dry milling technology. Economic allocation 95.6% to ethanol. CO2 emissions are allocated based on carbon balance.	Transport of potatoes to the distillery, processing to hydrated ethanol. System boundary at the distillery gate, dehydration not included.	2002-2005	Switzerland

Table 29 (cont'd)

Ethanol, 95% in H2O, from rye, at distillery/RER S - Ethanol, 95% in H2O, from rye, at distillery/RER U	Ecoinvent	97.7%	1 kg hydrated ethanol 95% (dry basis, i.e. 1.05 kg hydrated ethanol wet basis). Dry milling technology. Economic allocation 97.7% to ethanol. CO2 emissions are allocated based on carbon balance.	Transport of grains to the distillery, processing to hydrated ethanol. System boundary at the distillery gate, dehydration not included.	2002-2006	Europe
Ethanol, 95% in H2O, from sugar beet molasses, at distillery/RER S - Ethanol, 95% in H2O, from sugar beet molasses, at distillery/RER U	Ecoinvent	94.5%	1 kg hydrated ethanol 95% (dry basis, i.e. 1.05 kg hydrated ethanol wet basis). Dry milling technology. Economic allocation 97.7% to ethanol. CO2 emissions are allocated based on carbon balance.	Transport of molasses to the distillery, processing to hydrated ethanol. System boundary at the distillery gate, dehydration not included.	1998-2005	Switzerland

Table 29 (cont'd)

Ethanol, 95% in H2O, from sugar beets, at fermentation plant/CH S - Ethanol, 95% in H2O, from sugar beets, at fermentation plant/CH U	Ecoinvent		Allocation based on economic criteria.	Fermentation of sugar beets including materials, energy uses, infrastructure, and emissions.	Time of publications	Modeled for Switzerland with data from Finland
Ethanol, 95% in H20, from sugar cane, at fermentation plant/BR S - Ethanol, 95% in H20, from sugar cane, at fermentation plant/BR U	Ecoinvent		Allocation based on economic criteria.	Fermentation of sugar cane including materials, energy uses, infrastructure, and emissions.	Time of publications	Brazil

Table 29 (cont'd)

Ethanol, 95% in H20, from sugarcane molasses, at sugar refinery/BR S - Ethanol, 95% in H20, from sugarcane molasses, at sugar refinery/BR U	Ecoinvent	10-11%	1 kg hydrated ethanol 95% (dry basis, i.e. 1.05 kg hydrated ethanol wet basis). Dry milling technology. Economic allocation 97.7% to ethanol. CO2 emissions are allocated based on carbon balance.	Transport of sugarcane to the sugar refinery and the processing to ethanol. System boundary is at the sugar refinery. Treatment of waste effluents is not included (most waste water used on nearby fields).	1994-2006	Brazil
Ethanol, 95% in H20, from sweet sorghum, at sugar refinery/CN S - Ethanol, 95% in H20, from sweet sorghum, at sugar refinery/CN U	Ecoinvent	91.0%	1 kg hydrated ethanol 95% (dry basis, i.e. 1.05 kg hydrated ethanol wet basis). Dry milling technology. Economic allocation 97.7% to ethanol. CO2 emissions are allocated based on carbon balance.	Transport of sorghum to the distillery and the processing to ethanol. System boundary is at the sugar refinery. Treatment of waste effluents is not included (most waste water used on nearby fields).	1992-2005	China

Table 29 (cont'd)

Ethanol, 95% in H20, from whey, at sugar refinery/CH S - Ethanol, 95% in H20, from whey, at sugar refinery/CH U	Ecoinvent		Allocation based on economic criteria.	Fermentation of whey including materials, energy uses, infrastructure, and emissions.		Switzerland
Ethanol, 95% in H20, from wood, at sugar refinery/CH S - Ethanol, 95% in H20, from wood, at sugar refinery/CH U	Ecoinvent	99.7%	1 kg hydrated ethanol 95% (dry basis, i.e. 1.05 kg hydrated ethanol wet basis). Dilute acid pre-hydrolysis and simultaneous saccharification and co-fermentation. Economic allocation 97.7% to ethanol. CO2 emissions are allocated based on carbon balance.	Transport of wood to the distillery and the processing to ethanol. System boundary is at the sugar refinery. Dehydration is not included. Process heat and power supply is generated by unconverted solids.	1999-2006	Switzerland

Table 29 (cont'd)

Ethanol, 95% in H20, from wood, at sugar refinery/SE S - Ethanol, 95% in H20, from wood, at sugar refinery/SE U	Ecoinvent	99.7%	1 kg hydrated ethanol 95% (dry basis, i.e. 1.05 kg hydrated ethanol wet basis). Dilute acid pre-hydrolysis and simultaneous saccharification and co-fermentation. Economic allocation 97.7% to ethanol. CO2 emissions are allocated based on carbon balance.	Transport of wood to the distillery and the processing to ethanol. System boundary is at the sugar refinery. Dehydration is not included. Process heat and power supply is generated by unconverted solids.	1999	Sweden
Ethanol, 99.7% in H2O, from biomass, at distillation/BR S - Ethanol, 99.7% in H2O, from biomass, at distillation/BR U	Ecoinvent		Dewatering of ethanol 95%	Dewatering of ethanol 95%		Brazil
Ethanol, 99.7% in H2O, from biomass, at distillation/CH S - Ethanol, 99.7% in H2O, from biomass, at distillation/CH U	Ecoinvent		Modeled with ethanol production from sugar beets, whey and grass.	Dewatering of ethanol 95%, including ethanol mix.	2007	Switzerland

Table 29 (cont'd)

Ethanol, 99.7% in H2O, from biomass, at distillation/CN S - Ethanol, 99.7% in H2O, from biomass, at distillation/CN U	Ecoinvent		1 kg Sorghum-based ethanol. Molecular sieve technology used for dehydration.	Dehydration of hydrated ethanol (95%). Treatment of waste also included.	1992-2005	China
Ethanol, 99.7% in H2O, from biomass, at distillation/RER S - Ethanol, 99.7% in H2O, from biomass, at distillation/RER U	Ecoinvent		1 kg rye-based ethanol. Molecular sieve technology used for dehydration.	Dehydration of hydrated ethanol (95%). Treatment of waste also included.	2002-2006	Europe
Ethanol, 99.7% in H2O, from biomass, at distillation/US S - Ethanol, 99.7% in H2O, from biomass, at distillation/US U	Ecoinvent		1 kg corn-based ethanol. Molecular sieve technology used for dehydration.	Dehydration of hydrated ethanol (95%). Treatment of waste also included.	1990-2006	USA

Table 29 (cont'd)

Life cycle assessment of energy and GHG emissions during ethanol production from grass straws using various pretreatment processes	International Journal of LCA 2011		Ethanol from Tall Fescue grass straw by various methods: dilute acid, dilute alkali, hot water, steam explosion.	Grass seed production, straw collection and transportation, electricity and process energy. Conversion to ethanol: Biomass Preparation, pretreatment, conditioning (or hydrolysis), fermentation, distillation, waste water treatment, energy recovery from biogas.	2011	USA (Oregon)
Measuring ecological impact of water consumption by bioethanol using life cycle impact assessment	International Journal of LCA Jan 2012		Ecological impacts of corn based ethanol - water consumption in 81 spatially explicit Minnesota watersheds.	water consumption during corn production		USA (Minnesota)
Life cycle assessment of a bio-refinery concept producing bioethanol, bioenergy, and chemicals from switchgrass	International Journal of LCA Jan 2010		Bioethanol and coproducts from switchgrass.	Land use change, harvesting, transport to refinery, drying and palletizing, biorefinery functions. Also includes cultivation, seeding, fertilizer, herbicides, lime and direct emissions.	2010	Unspecified

Table 29 (cont'd)

Allocation issues in LCA methodology: a case study of corn stover based fuel ethanol	International Journal of Life Cycle Assessment 2009		Different allocation methods are used to assess sensitivity of result to allocation method. GHG, acidification, eutrophication, photochemical oxidation, ecotoxicity, abiotic depletion and ozone layer depletion are reported.	Agriculture: Seeding, energy, minerals, pesticides, fertilizers, inorganics and water (land use excluded). Cellulosic stage: pretreatment, hydrolyze fermentation, distillation, dehydration and evaporation.	2009	USA
Life Cycle Assessment of fuel ethanol from sugar cane in Brazil	International Journal of LCA May 2009		Functional Unit is 10,000 Km covered by car of a specific size engine, but data is broken into phases.	Soil preparation, cane plantation, chemical application, harvesting, fuel ethanol process, and energy co-generation	2009	Brazil
Regional variations in GHG emissions of bio-based products in the United States - Corn based ethanol and soybean oil	International Journal of LCA Sept 2009		Corn ethanol represents dry milling process, and Soybean oil was made using the crushing process. GHG only reported category. Data is at the county level, 40 counties in the US corn belt were chosen.	Direct land use change is included. It is measured and the change in soil carbon organic material. Includes impacts associated with the biomass, bio-refining, upstream processes.	2009	USA

Table 29 (cont'd)

Life Cycle Assessment of fuel ethanol from cane molasses in Thailand.	International Journal for LCA June 2008		Functional unit is gas equivalent consumed by a new passenger car to travel a specific distance. Sugar factory and ethanol data is primary.	Sugar cane production: land prep, new planting (once per crop rotation), crop maintenance, harvesting. Sugar milling, fermentation, distillation, dehydration	2008	Thailand
Life cycle assessment of fuel ethanol from cassava in Thailand	International Journal of Life Cycle Assessment March 2008		Reports ethanol as E85, but process contribution data is available for cassava production and ethanol conversion.	cassava farming: land prep, planting, crop maintenance, harvesting. Chip processing: chipping, dun dying, packing, milling, mixing and liquifying, fermentation, distillation, dehydration	2008	Thailand
Comparative LCA of two biofuels - ethanol from sugar beet and rapeseed methyl ester	International Journal of Life Cycle Assessment May 2008		GHG and particulates reported	Fertilizer, fuel, pesticides, drying, extraction, refining	2008	

Table 29 (cont'd)

Life cycle assessment of sugarcane ethanol and palm oil biodiesel joint production	Journal of Industrial Ecology Sept. 2012		Both sugarcane and palm tree are crops with high biofuel yields. The joint production of these crops enhances the sustainability of ethanol. For the purpose of this study, three sugarcane mills in Sao Paulo State and one palm oil refinery in Para State were surveyed (Brazil). Results showed that fossil fuel use and greenhouse gas emissions decreased when the joint production system was compared to the traditional sugarcane ethanol production system. As a result, energy efficiency increased.		2012 (publication)	Brazil

Table 29 (cont'd)

Bioproduction from Australian sugarcane: an environmental investigation of product diversification in an agro-industry	Journal of cleaner production Vol 39			Land use change, milling and production, fermentation, additional cane growing (for scenarios 3 and 4).	2012	Australia
Effect of biogas utilization and plant co-location on life cycle greenhouse gas emissions of cassava ethanol production	Journal of cleaner production Vol 37		For the purpose of this study, three sugarcane mills in Sao Paulo State and one palm oil refinery in Para State were surveyed (Brazil).	Cassava farming: Land prep, seed planting, fertilizer, weeding, harvesting. Cassava chip production: weight and measure of harvested roots, chopping and drying, transport to ethanol plant. Fuel production: pre-treatment, liquefying, saccharification.	2012	Thailand
Agricultural crop based biofuels - resource efficiency and environmental performance including direct land use changes	Journal of Cleaner Production Vol 19		Ethanol from wheat, sugar beet, and willow. Methyl ester from rape and methane from corn.	GHG emissions and Direct land use changes.	2011	Northern Europe

Table 29 (cont'd)

Improvements in Life Cycle Energy Efficiency and Greenhouse Gas Emissions of Corn-Ethanol	Journal of Industrial Ecology, Feb. 2009			Energy used for feedstock production and harvesting, including fossil fuels for field operations and electricity for grain drying and irrigation.	2009 (published)	USA
Life cycle inventory and energy analysis of cassava based fuel ethanol in china	Journal of Cleaner Production Vol 16 (2007)		Results showed that fossil fuel use and greenhouse gas emissions decreased when the joint production system was compared to the traditional sugarcane ethanol production system. As a result, energy efficiency increased.	Cassava cultivation and treatment: seed production, field prep and plough, sowing, fertilizer, weed control, harvesting, pilling and slicing, insolation and packing. Conversion from dry chips: Milling, mixing, liquification and saccharification, fermentation, distilling, separation, rectification and dehydration. Denaturing included.	2007	China
Ethanol, 99.7% in H2O, from wood, at distillation/SE S - Ethanol, 99.7% in H2O, from wood, at distillation/SE U	Ecoinvent		Ethanol from Scandinavian softwood chips	Dewatering of ethanol 95% from Scandinavian wood		Sweden

Table 29 (cont'd)

Synthetic gas, from wood, at fixed bed gasifier/CH S - Synthetic gas, from wood, at fixed bed gasifier/CH U	Ecoinvent		Composition (%mol) of the resulting gas is 28.4% H2, 40.6% CO, 23.6% CO2, 5.9% CH4, and 1.5 CnHm on a nitrogen and water free basis. Nitrogen content is 47.6%. Density is 1.15 kg/Nm3. Lower heating value of the gas is 5.4 MJ/Nm3. Production of 1 Nm3 syngas.	Conversion of wood chips into synthetic gas. Includes drying and further comminution of wood chips (down to size 30x30x30mm), fluidized bed gasification, treatment of the resulting syngas to remove impurities and contaminants.	1995-2004	Switzerland
Synthetic gas, from wood, at fluidized bed gasifier/CH S - Synthetic gas, from wood, at fluidized bed gasifier/CH U	Ecoinvent		Composition (%mol) of the resulting gas is 15.5% H2, 39.2% CO, 34.9% CO2, 8.7% CH4, and 1.7 CnHm on a nitrogen and water free basis. Nitrogen content is 50.4%. Density is 1.15 kg/Nm3. Lower heating value of the gas is 5.4 MJ/Nm3. Production of 1 Nm3 syngas.	Conversion of wood chips into synthetic gas. Includes drying and further comminution of wood chips (down to size 30x30x30mm), fluidized bed gasification, treatment of the resulting syngas to remove impurities and contaminants.	1995-2004	Switzerland

Table 29 (cont'd)

Synthetic gas, production mix, at plant/CH S	Ecoinvent		Wood gasification in CH is limited to the fixed bed pilot plant experience (Pyroforce, Xylowatt). Average composition (% mol) is 22.0% H2, 39.9% CO, 29.3% CO2, 7.3% CH4, 1.6% CnHm on a nitrogen and water free basis. Nitrogen content is 49.0%. Density is 1.15 kg/Nm3.	Production of synthetic gas from wood chips. 50% fixed gasification, 50% fluidized gasification.	1995-2004	Switzerland
Soy biodiesel, production, at plant	USLCI		"CARBON SEQUESTRATION should be accounted for after the product is built in its LCA model, and should be included depending on the use of end of life fate of that product."(USLCI)	Materials, process energy, water, transport,		North America

Table 29 (cont'd)

Potential for production and use of rapeseed biodiesel. Based on a comprehensive real-time LCA case study in Denmark with multiple pathways	International Journal of LCA 2012		Specific Denmark case, reports 6 impact categories.	Rape seed production, storage, processing, transport, energy requirements, co-products.	2012	Denmark
Life cycle assessment of biodiesel in Costa Rica	University of Applied Sciences Northwestern Switzerland (FHNW)					Costa Rica

Table 29 (cont'd)

Life cycle assessment of soybean based biodiesel production in Argentina	International Journal of LCA March 2009		Primary data was obtained for the crop portion of the data only.	Only CO2, CH4, and N2O were considered in the global warming calculation. Land use change except for direct de-forestation is excluded. Storage and drying is excluded. Agriculture, extraction and refining, trans esterification included.	2001-2005	Argentina
Life Cycle Analysis of Algae Biodiesel	Sander and Murthy 2010 – International Journal of LCA		Goal to provide baseline information about algae biodiesel. Data was taken from USLCI and literature sources. Many assumptions / substitutions were made to estimate an LCA for Algae biodiesel. Open pond growth assumed. Soybean processing data used to estimate the conversion of algal lipids into biodiesel, and algae meal was assumed to have the same ethanol yield as wheat straw.	Algae growth, harvesting, separation, processing, transportation and distribution included. Partial treatment of wastewater and natural gas requirements also included.	Time of publications	Unspecified

Table 29 (cont'd)

The life cycle assessment of biodiesel from palm oil ("dende") in the Amazon	Journal of Biomass andBioenergy, Jan. 2012		Palm oil as a promising source of biodiesel in the Amazon			Brazil
Food, Fuel and Climate Change: Is palm based biodiesel a sustainable option for Thailand?	Journal of Industrial Ecology July 2012		Uses an indicator called "net feedstock balance" that describes the physical supply of feedstock for the long term. This is a "well to wheels" study, but unit process data is available for land use change scenarios and how they affect GHG emissions. Only 100 year GWP reported.	Land use change, palm oil cultivation and harvesting, transport, milling , biodiesel conversion, by product processing, on site waste management, and use of biodiesel in a vehicle included.	2012	Thailand
A life cycle assessment of biodiesel production from winter rape grown in Southern Europe	Journal of Biomass and Bioenergy May 2012		Compares conventional diesel with biodiesel production from winter rape crop. LCA evaluates the energy balance and the environmental impacts.			Southern Europe

Table 29 (cont'd)

Biogenic greenhouse gas emissions linked to the life cycles of biodiesel derived from European rapeseed and Brazilian soybeans	Journal of Cleaner Production 2009				2009	Brazil and Europe

Table 30 – Chemical Data Summary Inputs

Name	Materials	Transport	Infrastructure	Waste Treatment	Machines	Extraction	Process Energy	Drying	Fermentation	Refining	Direct Emissions	Storage	Water	Land Use
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Ethanol, denatured, forest residues, thermochemical	1			1			1						1	
Ethanol, denatured, corn stover, biochemical	1			1			1						1	
Ethanol, denatured, wheat straw, biochemical	1			1			1						1	
ethanol, denatured, mixed feedstocks, at conversion facility, 2022	1													
Ethanol, denatured, switchgrass, biochemical	1			1			1						1	

Table 30 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Ethanol, denatured, corn dry mill														
Corn, in distillery														
Ethanol, 95% in H2O, from corn, at distillery/US S - Ethanol, 95% in H2O, from corn, at distillery/US U		1					1							
Ethanol, 95% in H2O, from grass, at fermentation plant/CH S - Ethanol, 95% in H2O, from grass, at fermentation plant/CH U	1		1						1		1			
Ethanol, 95% in H2O, from potatoes, at distillery/CH S - Ethanol, 95% in H2O, from potatoes, at distillery/CH U		1					1							

Table 30 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Ethanol, 95% in H2O, from rye, at distillery/RER S - Ethanol, 95% in H2O, from rye, at distillery/RER U		1					1							
Ethanol, 95% in H2O, from sugar beet molasses, at distillery/RER S - Ethanol, 95% in H2O, from sugar beet molasses, at distillery/RER U		1					1							
Ethanol, 95% in H2O, from sugar beets, at fermentation plant/CH S - Ethanol, 95% in H2O, from sugar beets, at fermentation plant/CH U	1		1				1				1			

Table 30 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Ethanol, 95% in H20, from sugar cane, at fermentation plant/BR S - Ethanol, 95% in H20, from sugar cane, at fermentation plant/BR U	1		1				1				1			
Ethanol, 95% in H20, from sugarcane molasses, at sugar refinery/BR S - Ethanol, 95% in H20, from sugarcane molasses, at sugar refinery/BR U		1					1							
Ethanol, 95% in H20, from sweet sorghum, at sugar refinery/CN S - Ethanol, 95% in H20, from sweet sorghum, at sugar refinery/CN U		1					1							

Table 30 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Ethanol, 95% in H20, from whey, at sugar refinery/CH S - Ethanol, 95% in H20, from whey, at sugar refinery/CH U	1		1				1				1			
Ethanol, 95% in H20, from wood, at sugar refinery/CH S - Ethanol, 95% in H20, from wood, at sugar refinery/CH U		1					1							
Ethanol, 95% in H20, from wood, at sugar refinery/SE S - Ethanol, 95% in H20, from wood, at sugar refinery/SE U		1					1							
Ethanol, 99.7% in H2O, from biomass, at distillation/BR S - Ethanol, 99.7% in H2O, from biomass, at distillation/BR U								1						

Table 30 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Ethanol, 99.7% in H2O, from biomass, at distillation/CH S - Ethanol, 99.7% in H2O, from biomass, at distillation/CH U								1						
Ethanol, 99.7% in H2O, from biomass, at distillation/CN S - Ethanol, 99.7% in H2O, from biomass, at distillation/CN U								1						
Ethanol, 99.7% in H2O, from biomass, at distillation/RER S - Ethanol, 99.7% in H2O, from biomass, at distillation/RER U								1						
Ethanol, 99.7% in H2O, from biomass, at distillation/US S - Ethanol, 99.7% in H2O, from biomass, at distillation/US U								1						

Table 30 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Life cycle assessment of energy and GHG emissions during ethanol production from grass straws using various pretreatment processes	1	1		1			1		1					
Measuring ecological impact of water consumption by bioethanol using life cycle impact assessment														
Life cycle assessment of a bio-refinery concept producing bioethanol, bioenergy, and chemicals from switchgrass	1	1						1			1			
Allocation issues in LCA methodology: a case study of corn stover based fuel ethanol	1						1	1	1				1	

Table 30 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Life Cycle Assessment of fuel ethanol from sugar cane in Brazil	1						1		1					
Regional variations in GHG emissions of bio-based products in the United States - Corn based ethanol and soybean oil	1						1	1	1					1
Life Cycle Assessment of fuel ethanol from cane molasses in Thailand.	1						1	1	1	1				
Life cycle assessment of fuel ethanol from cassava in Thailand	1					1	1	1	1	1				
Comparative LCA of two biofuels - ethanol from sugar beet and rapeseed methyl ester	1					1	1	1		1				

Table 30 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Life cycle assessment of sugarcane ethanol and palm oil biodiesel joint production														
Bioproduction from Australian sugarcane: an environmental investigation of product diversification in an agro-industry	1					1	1		1					1
Effect of biogas utilization and plant co-location on life cycle greenhouse gas emissions of cassava ethanol production	1	2				1	1	1						
Agricultural crop based biofuels - resource efficiency and environmental performance including direct land use changes	1													1

Table 30 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Improvements in Life Cycle Energy Efficiency and Greenhouse Gas Emissions of Corn-Ethanol														
Life cycle inventory and energy analysis of cassava based fuel ethanol in china	1					1	1	1	1	1				
Ethanol, 99.7% in H2O, from wood, at distillation/SE S - Ethanol, 99.7% in H2O, from wood, at distillation/SE U								1						
Synthetic gas, from wood, at fixed bed gasifier/CH S - Synthetic gas, from wood, at fixed bed gasifier/CH U		1				1						1		

Table 30 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Synthetic gas, from wood, at fluidized bed gasifier/CH S - Synthetic gas, from wood, at fluidized bed gasifier/CH U							1	1		1				
Synthetic gas, production mix, at plant/CH S														
Soy biodiesel, production, at plant	1	1					1						1	
Potential for production and use of rapeseed biodiesel. Based on a comprehensive real-time LCA case study in Denmark with multiple pathways	1	1		1			1					1		
Life cycle assessment of biodiesel in Costa Rica														

Table 30 (cont'd)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Life cycle assessment of soybean based biodiesel production in Argentina	1					1	1			1				
Life Cycle Analysis of Algae Biodiesel	1	1		1			1	1						
The life cycle assessment of biodiesel from palm oil ("dende") in the Amazon														
Food, Fuel and Climate Change: Is palm based biodiesel a sustainable option for Thailand?	1	1		1		1	1							1
A life cycle assessment of biodiesel production from winter rape grown in Southern Europe														
Biogenic greenhouse gas emissions linked to the life cycles of biodiesel derived from European rapeseed and Brazilian soybeans	1													

Table 31 – Polymer Data Summary

Name	Data Availability	Details	Includes	Data Years	Data Country
Modified starch, at plant/RER S - Modified starch, at plant/RER U	Ecoinvent	Production of 1 kg granulate modified starch, highly aggregated background data used.	Only highly aggregated data were available, therefore emissions from energy consumption, waste water treatment and raw material inputs have been subtracted resulting in a difference in NMVOC emissions. Production of input material corn starch and fossil components (plasticizers and complexing agents), transports of input materials, energy consumption in the processing and packaging at plant as well as waste treatment.		Europe
Polylactide, granulate, at plant/GLO S - Polylactide, granulate, at plant/GLO U	Ecoinvent	Production of 1 kg PLA, based on data from world's largest PLA plant. The inventories include the LCI data from the report of the producer NatureWorks. Only aggregated data are reported.	Only highly aggregated data were available, therefore emissions from energy consumption, waste water treatment and raw material inputs have been subtracted resulting in a difference in NMVOC emissions. Maize production, energy use, transport and waste water treatment. Infrastructure has been added. Wind power used to offset CO2 emissions.		USA (Nebraska)

Table 31(cont'd)

Polylactide Biopolymer Resin, at plant	USLCI	Data has been peer reviewed by Dr. I. Boustead from Boustead Consulting, UK. Data only represents Ingeo polylactide (PLA) resin production by NatureWorks LLC in Blair Nebraska and cannot be used for PLA production in general. Final review report is attached to the Data Module Report.	Materials, waste disposal, electricity, natural gas, water, transport.		USA (Nebraska)
Soy-based resin, at plant	USLCI	" CARBON SEQUESTRATION should be accounted for after the product is built in its LCA model, and should be included depending on the use of end of life fate of that product"(USLCI).	Materials, waste disposal, process energy, water		USA
An ecoprofile of thermoplastic protein derived from blood meal Part 2: thermoplastic processing	International Journal of LCA 2012	Thermoplastic processing of NTP derived from bloodmeal into pellets.	Heating, agitating, rolling, mixing, extruding, pelletizing, cooling.	2012	New Zealand

Table 31(cont'd)

Environmental impacts of conventional plastic and bio-based carrier bags part 1: life cycle production	International Journal of LCA March 2010	This study is for Singapore, but the PHA bags are manufactured in the US and transported vs. the PE bags which are manufactured in Singapore, this difference means there is a long transport step included for the PHA bags but not the PE bags.	Corn production, wet milling, fermentation and recovery, blown film extrusion, ship transport, road transport		USA (shipped to Singapore)
A Comparative Life Cycle Assessment Study of PE Based on Sugar Cane and Crude Oil	Journal of Industrial Ecology, June 2012	Study goal: identify major contributors to the environmental impact of sugar cane-based LDPE and to compare the environmental performance of sugar cane LDPE produced in Brazil and used in Europe with the performance of fossil-based LDPE produced and used in Europe. Land Use Change (LUC) emissions were also accounted for.	Land use change, ethanol production, polymerization, and transport of polymer by cargo ship.	2012 (published)	Brazil

Data summary table references: [3, 7, 9, 10, 13, 17, 21, 24-27, 29-32, 35-94]

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