Swiss Centre for Life Cycle Inventories

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Life Cycle Inventories of Bioenergy

Data v2.0 (2007)

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Project "Ökobilanz von Energieprodukten”

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TP1: Life Cycle Inventories of Bioenergy

Authors: Mike Chudacoff, Chudacoff Ökoscience
Arnaud Dauriat, ENERS
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Reviewer: Niels Jungbluth, ESU-services Ltd.
Arnaud Dauriat, ENERS

TP1.b: Life Cycle Inventories of Imported Fuels

Authors: Arnaud Dauriat, ENERS
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Reviewer: Niels Jungbluth, ESU-services Ltd.
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TP1.c: LCI of modern biogas plants and organic rape seed

Authors: Fredy Dinkel, Carbotech
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Konrad Schleiss, Umwelt- und Kompostberatung, Grenchen

Reviewer: Niels Jungbluth, ESU-services Ltd.

Citation:
Jungbluth, N., Chudacoff, M., Dauriat, A., Dinkel, F., Doka, G., Faist Emmenegger, M., Gnansounou, E., Kljun, N., Schleiss, K., Spielmann, M., Stettler, C., Sutter, J. 2007: Life Cycle Inventories of Bioenergy. ecoinvent report No. 17, Swiss Centre for Life Cycle Inventories, Dübendorf, CH.

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A further co financing from alcosuisse, Erdöl-Vereinigung, and Entsorgung und Recycling Zürich made it possible to investigate a number of further datasets. Furthermore the collaboration with industrial partners, non governmental organisations and public authorities in the review group helped to improve the quality of the investigated datasets. We thank all people involved in the review work.

The data have first been used and evaluated by the EMPA St. Gallen for their LCA study of different biofuel production chains (Dinkel 2007; Kägi et al. 2007; Zah et al. 2007). We thank the authors of these reports for further comments and hints on possible errors.

Summary

Today, transportation relies almost entirely on oil-based fuels and is responsible for about 30% of the world's fossil fuel consumption. According to the principles of sustainability, a modern society should preserve non-renewable energy sources and replace them with renewable energy. The depletion of fossil energy reserves and the associated environmental impacts are the two main reasons that lead to consider the use of alternative fuels in the sector of transportation.

Fuels derived from biomass, also referred to as biofuels, are not only potentially renewable, but are also sufficiently similar to fossil fuels (which also have their origin in biomass) to provide direct substitution. It seems also to be a promising alternative to fossil fuels in the short term.

The goal of this project, which has been initiated by the Swiss Federal authorities BFE, BLW and BAFU, is to investigate life cycle inventory data of several energy products from biomass. These data shall complement existing datasets in the ecoinvent database and should become available in a future version of this database. Therefore the same methodology is used as in the ecoinvent project (Frischknecht et al. 2007a).

Some types of biomass and their energy products have already been investigated for the ecoinvent database, e.g. agricultural products (Nemecek et al. 2007), renewable materials (Althaus et al. 2007b) or wood products (Werner et al. 2007) as well as their use in combustion processes (Bauer 2007). Nevertheless many possible uses of biomass for energy purposes were so far not covered by the database.

Fig. 1.1 provides a systematic overview for the different types of bioenergy that are of interest. In general, four stages of production can be distinguished (provision of the biomass, conversion to a fuel, distribution and use).

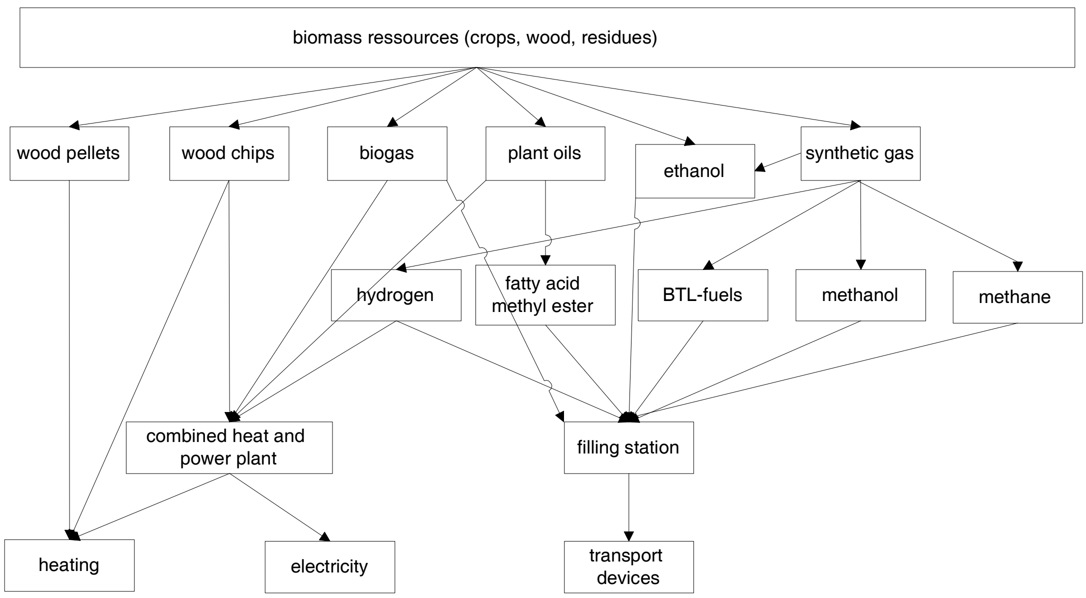

Fig. 1.1 Overview for the most important bioenergy products and their possible uses

In a pre-study the existing datasets of the ecoinvent database have been systematically organized (Jungbluth & Frischknecht 2004). The study helped to identify all missing process chains and unit processes in order to be able to define the bioenergy products of interest for the situation in Switzerland.

The following products are already covered with the ecoinvent data v1.2:

- Forestry
- Agricultural products from Switzerland

- Wood fuels
- Use of wood for heating and CHP

Within the first part of this project, the production and use of ethanol, biogas, BTL-fuels (biomass to liquid i.e. methanol) and plant oils have been investigated. Therefore agricultural products that are needed for these fuels (grass, straw, rape seeds) are included in the analysis. The use of biofuels in different means of transportation is investigated as well.

In the second part of the project a specific focus has been laid on biofuels imported to Switzerland. Therefore basic LCI data have been collected for biomass production and biofuel conversion in different countries. In this part of the project also to day and future conventional transport means have been included in the analysis.

In a third part of the project an inventory has been investigated for modern biogas plant with a cover on the storage which minimizes the methane emission. Also preliminary data for organic rape seed have been revised.

The calculation of cumulative results is based on ecoinvent data v1.2 (or partly ecoinvent data v1.3). It has been executed by the ecoinvent Manager with a copied version of the original database and with the same calculation routines.

It was not possible to cover all possible uses of bioenergy within this project due to financial limitations. The most important gaps that remain are the following:

- Full investigation of all possible production routes. Only the most important routes have been investigated.
- Use of some bioenergy carriers, e.g. plant oil, in heating and combined heat- and power plants.

In the impact assessment part of the project different options for the use of bioenergy are compared and analysed in a full life cycle assessment (Dinkel 2007; Kägi et al. 2007; Zah et al. 2007).

Zusammenfassung

Im Rahmen von verschiedenen Studien wurden bis heute Energieprodukte hinsichtlich ihrer Umweltauswirkungen untersucht. Dabei wurden nicht erneuerbare (fossile) Energieträger untereinander, aber auch mit erneuerbaren verglichen. Die Untersuchungen aus der Schweiz beschränken sich jedoch meist auf einzelne Umweltbereiche oder beleuchten nur einzelne Aspekte der Umweltauswirkungen. Zudem sind bei biogenen Energieträgern die Anbaumethoden und -varianten nicht systematisch untersucht worden.

Um einerseits im Forschungsprogramm Biomasse die richtigen Schwerpunkte setzen zu können und andererseits in der politischen Diskussion im Bereich Energie-, Umwelt- und Klimapolitik über die entsprechenden Entscheidungsgrundlagen zu verfügen, werden umfassende Ökoinventare von (Bio-)Energieprodukten erarbeitet, die alle relevanten Umweltbereiche gleichermassen berücksichtigen und sowohl biogene als auch fossile Energieträger umfassen.

In der Datenbank ecoinvent gibt es bereits zahlreiche Datensätze zu diesem Thema, z.B. zu

- Holzprodukten und Holzbrennstoffen
- Landwirtschaftsprodukten aus der Schweiz
- Holzheizungen und Kraftwerke

Die Ökoinventare sind modular (Prozesse bzw. Prozessketten) aufgebaut, sodass eine Erweiterung und eine Bilanzierung von weiteren Anwendungsfällen einfach möglich ist. Folgende Wertschöpfungsebenen werden dabei unterschieden:

- Landwirtschaftliche und forstwirtschaftliche Produktion (bzw. Bereitstellung von Reststoffen und Nebenprodukten)
- Verarbeitung, Herstellung der Brenn- und Treibstoffe
- Evtl. Bestimmung eines Produktionsmixes
- Distribution bis zum Endverbraucher
- Verwendung der Energieträger für Fahrzeuge, Heizungen, etc.

Im ersten Teilprojekt (TP1, „LCI bioenergy") wurden fehlende Sachbilanzdaten für alle wichtigen Produktionsstufen und Verfahren erhoben soweit sie nicht schon bisher Bestandteil der ecoinvent Daten v1.2 waren. Dabei wurden die Themen „**Biogas**", „**Ethanol**", „**BTL/synthetische Treibstoffe**", „**Öl**", „**Transport**„ und „**Sonstige**" bearbeitet.

Im zweiten Teilprojekt (TP1.b, „LCI of imported fuels") lag der Schwerpunkt dann auf der Bilanzierung von Treibstoffen, die u.U. in die Schweiz importiert werden können. Ausserdem wurden noch fehlende Inventare für die Schweiz nacherhoben und aktuelle Transportprozesse untersucht.

Im dritten Teilproject (TP1.c Biogas) wurde ein neuer Datensatz für moderne landwirtschaftliche Biogasanlagen mit Abdeckung der Nachgärung bilanziert. Diese minimiert die Methanemissionen. Ausserdem wurde der Datensatz für biologisch angebauten Raps mit neuen Daten überarbeitet.

Die Erhebung erfolgt entsprechend der Qualitätsrichtlinien für das ecoinvent Projekt (Frischknecht et al. 2007a).

Erhoben werden nur die notwendigen Grundlagendaten der wichtigsten Prozessschritte für die Bereitstellung von Biomasse-Energieträgern. Es werden jedoch nicht alle Varianten gerechnet (z.B. Lkw mit Ethanol aus Mais (Bio/IP) und Lkw mit Ethanol aus Weizen Bio/IP) sondern jeweils nur Durchschnittsbetrachtungen auf der Nachfolgeebene durchgeführt (z.B. nur Lkw betrieben mit Ethanol-Produktionsmix).

Im zweiten Teil des Gesamtprojektes werden die erhobenen Daten in einer Gesamtökobilanz bewertet und verschiedene Treibstoffe und Herstellungswege miteinander verglichen (Kägi et al. 2007; Zah et al. 2007).

Table of Contents

Part I

I. Methodological Remarks

Author: Niels Jungbluth, Mireille Faist Emmenegger, ESU-services Ltd.

Citation:
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1 Introduction

1.1 Goal of the project

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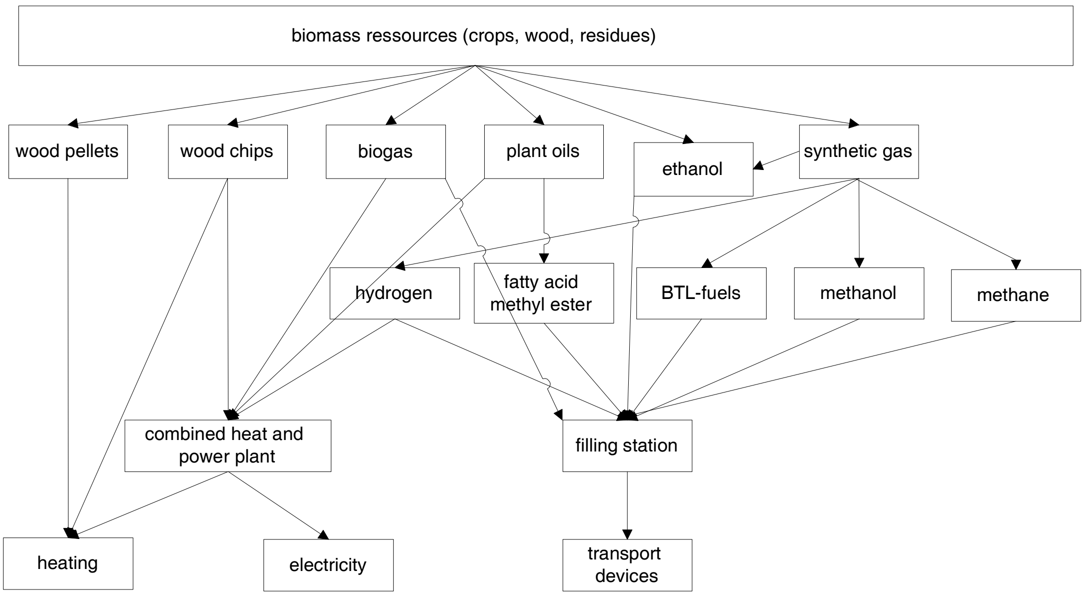

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In a second part of the project different options for the use of bioenergy are compared and analysed in a full life cycle assessment (Dinkel 2007; Kägi et al. 2007; Zah et al. 2007).

1.2 Natural conditions for biomass production in Switzerland

Switzerland has an area of 41'285 km^2. Jura, Lowlands and the Alps are the three geographical main regions. Switzerland has a very high population density: on average, about 183 people live on 1 km2. The difference between the regions are however high: in the Alps, which have a great share of the country’s surface, lives only about 10% of the population.[1]

The alpine arch has a length of 800 km and a broadness of ca. 200 km as well as an average altitude of 2500 m over sea and acts as a climate barrier. Climate in the Swiss Alpine region is divided in the North and the South region. In the Northern part of the Alps maritime climate is dominating. The Southern part of the Alps is dominated by Mediterranean climate, which mean milder winters. Some valleys are protected against Northern and Southern precipitation activities. Consequence is a dry climate: typical for this kind of climate are Unterwallis and Engadin valleys.[2]

The following table gives some key figures of the climate in Switzerland in 2003.

[1] http://www.swissworld.org/ger/swissworld.html?siteSect=201&sid=4147667&cKey=1061372946000&rubricId=10010

[2] source: Meteoschweiz, www.meteoschweiz.ch

Tab. 1.1 Key figures of the climate in Switzerland (average 1961-1990).

	altitude	Sunshine duration	Precipitation quantity	Temperature of air (year average)
	m. o. s.	h	mm	°C
Basel	316	1599	778	9.6
Bern	565	1638	1028	8.2
Chur	555	1702	814	8.7
Davos	1590	1680	1082	2.8
Genève	420	1694	970	9.8
Locarno Monti	366	2155	1668	11.5
Lugano	273	2026	1545	11.6
Luzern	456	1322	1171	8.8
Neuchâtel	485	1549	932	9.3
Sion	482	1990	598	9.2
St Gallen	779	1390	1248	7.4
Zürich	556	1482	1086	8.5

source: http://www.meteoschweiz.ch/de/Daten/Messwerte/IndexMesswerte.shtml, downloaded 3.10.2005

The length of growing period is 115-180 days in the Subalpine zone (1700-2400 m.o.s.) and 180-245 days in the mountainous zone (1000-1700 m.o.s.). Typical soils in the Alps are silica rocks with little humus.

1.3 Reserves and resources for bioenergy in Switzerland

Switzerland has mostly small sized farms with an average of 16.2 ha (19.9 ha when considering only full-time farmers). The intensity of production is therefore relatively low. Due to climatic differences between Lowlands and Alps and between South and North, the agriculture is regionally specialised. In the Alps there is mostly animal production as well as forestry.

Agriculture in the Alps is strongly dependent from subsidies. Subsidies are however linked to ecological requirements. Agriculture in the Lowlands is e.g. following the principles of integrated production (IP) as a consequence of the policy on subsidies. About 10% (102'000 ha in 2002 from the total of 1.07 Mio ha) is organic agriculture (mainly grasslands).[3] Important amounts of agricultural products, e.g. fodder and food are imported to Switzerland. Cheese is an important exported product.

Agriculture in Switzerland employs about 200'000 persons.[4] Hersener and Meier (1999) assume that fallow land will grow to 6’000 ha in 2010. This increase takes place at the expense of meadows.

Due to the nature of its mountainous landscape, Switzerland is a country of large forested lands. Forest residues are the primary biomass resource in Alpine countries. Wood industry by-products are widely used for energy production in the wood processing industry, district heating and for pellets production. Wood industry by-products potentials for transportation fuels are limited. No straw surplus for energy uses exists due to the fact that all straw is used for agricultural purposes.

In the most actual study for Switzerland (BFE/EWG 2004) the authors use several definitions of potential:

- Supply potential (Angebotspotential): generic term for theoretical biomass potential and realisable resp. ecological potential biomass potential for energy use.

[3] http://www.biodiversitymonitoring.ch/pdfs/M5_Datensatz_V2.pdf, 3.5.05

[4] http://www.bauernverband.ch/de/markt_preise_statistik/betrieb/se_2003_0112.pdf, figure for 2003, 3.5.05

- Theoretical (biomass) potential: grown biomass on arable land and material from secondary production thereby incurred in national economy.
- Ecological net production potential: biomass that can be produced on a sustainable and efficient (positive energy balance) way in the agriculture and forestry.
- Potential of disposal with energy recovery: share of industrial and urban biomass residues and waste that can be used for production of energy.

1.3.1 Energy crops

Several energy crops can possibly grow in Switzerland. Hersener and Meier (1999) calculate with following yields for energy crops:

- Rapeseed 3 t DM/ha
- Miscanthus 18 t DM/ha
- Hemp 12 t DM/ha
- Kenaf 3 t DM/ha
- Buffer area 3 t DM/ha

According to (BFE/EWG 2004), the share of energy crops is expected to increase to 5% of the open agricultural crop land, which corresponds to 20’000 ha until 2025, with a yield of about 10 t DM/ha. From 2025 to 2040 the authors evaluate the increase to be 10% of the open agricultural crop land, which corresponds to 45’000 ha. This increase occurs at the expense of intensively farmed crops like turnips, cereals, maize and intensive meadows.

1.3.2 Meadows

This category includes fallow land, extensive farmed meadows and permanent meadows (which have the biggest share of this category). Alpine meadows' potential is considered in the category "a) forest", as the increase in forest area occurs at the expense of alpine meadows. The yield of meadows for energy use is estimated by the authors of (BFE/EWG 2004) at 1% of yearly total yield until 2025. Optimistic scenarios evaluate the potential to be 3%.

1.3.3 Agriculture residues

Arable land in Switzerland covers 26% of agricultural land. Cereals are not dominant.

Tab. 1.2 Cereal production in Switzerland (Hersener & Meier 1999)

Arable land	Cereal area	Cereals share in arable land	Cereals yields 1998-2002
1000ha	1000ha	%	t/ha
413	136.1	30	6.1

The following agricultural products and residues for energy use are taken into consideration in Switzerland[5]:

- Rape seed oil, miscanthus, hemp, grass, hedges

[5] Personal communication, Hersener J.-L., Wiesendangen, Email 3.6.2004.

- Products from landscape care (areas of nature protection, residues of mowing of reeds etc.),
- Straw and other harvest residues.

Actually about 3,700 t DM (dry matter) of agricultural products (0.1 PJ) and 7,800 t DM (0.1 PJ) agricultural residues are used for energy production in Switzerland. This corresponds to 0.2 PJ primary energy. Hersener evaluate that the total potential of agricultural products is up to 305'000 t DM (4.6 PJ), of products of landscape care to 25'000 t DM (0.4 PJ) and agricultural residues to 38'000 t DM (0.6 PJ). This would raise available primary energy to 5.6 PJ. The ecological potential of agricultural products and residues in the future is estimated at 5.6 PJ (Hersener & Meier 1999).

Straw is used in Switzerland for litter and must even be imported (Hersener & Meier 1999). There is no straw surplus in Switzerland. Straw in dung from litter can be used as energy, however only in power plants bigger than at least 500 kWth. Due to the structure of agriculture and restricted possible sites, the share of straw, which can be used as energy in dung, must be estimated to be only 1% (Hersener & Meier 1999).

1.3.4 Forestry

Actually, about 10% of the Swiss forests are used for energy production. The total energy in biomass products of forests, orchards and vineyards was 17.7 PJ in 1998. The forest has two kinds of potentials: an increase in the harvest use and an increase in the harvest itself. From the first one ($1.8*10^6$ m^3 harvested wood that actually stay in the forest) the potential is evaluated to be about $1.2*10^6$ m^3 (2/3 of this quantity), which corresponds to about 9 PJ/a. For the second potential the authors calculate with the $4.2*10^6$ m^3 of forest increment that are at present not harvested. From these also 2/3 are evaluated to be possible to harvest, which represent 21.7 PJ/a. Production of bark in the year 1999 was at the level of 0.7 Mm^3 (4.83 PJ) and utilization for energy at 0.4 Mm^3. Thus surplus of bark that could be used equals 0.3 Mm^3 (2.07 PJ) (Hersener & Meier 1999).

For woody crops and hedges the potential is evaluated to be $0.35*10^6$ m^3, which corresponds to 2.8 PJ/a.

With an increase in the degree of utilization of forest area, groves, orchards and vineyards, the potential of biomass in the future would be 44 PJ, thereof the biggest share would be from forest areas (BfS/BUWAL 2003).

1.3.5 Wood industry by-products

The recycling rate of paper and waste wood as well as utilization grade is already high, so that there is only little potential of increase for this category. Some studies estimate that waste wood and waste from the paper/cardboard industry used for energy production amounted to 21 PJ in 2001. The possible increase in the degree of utilization of these residues is estimated as low, as recovery grade and utilization grade are already quite high (Hersener & Meier 1999). Therefore the calculated ecological potential for 2040 is 24.2 PJ, only 3.4 PJ more than in 2001.

According to national studies (BfS/BUWAL 2003) wood industry by-products production amounts to about 0.8 Mm^3. These are already fully used.

1.3.6 Whey

About 1.5 mio. m^3 of whey are produced in Switzerland per year (Binggeli & Guggisberg 2004; Scheurer & Baier 2001). Actually about 90% of waste of the food industry goes to the animal husbandry and is used as fodder (Scheurer & Baier 2001). Alternative use for whey is the production of biogas or bioethanol. According to (BFE/EWG 2004), the actual use of food industry waste for energy production is about 3% (of all waste). They expect this share to stay quite constant and grow only to 5%. The same study cites other (more optimistic) sources which expect the share of food industry waste for energy production to grow to 20%.

1.3.7 Development perspectives

The position paper of the Swiss Agency for Environment, Forests and Landscape (SAEFL) on the energetic use of energy crops shows that the intensive production is not favoured any more. The energetic use of energy crops from extensively farmed areas like meadows, ecological buffer area, set-aside land etc. is however welcomed (Binggeli & Guggisberg 2003).

In the context of a common project of the Swiss Federal Office for Energy with the Swiss Agency for Environment, Forests and Landscape, the most important process chains of the production of energy out of biomass have been studied and compared. The experiences with pilot and demonstration plants show that the general framework is of great importance for the development of the energetic use of biomass. The following points are discussed to promote and increase the use of biomass for energy production:

- Electricity redelivery tariff, tax on CO_2, promoting programs
- Exemption of tax for biofuels
- General promoting of biofuels and their sources

1.3.8 Economical feasibility

BFE/EWG (2004) studied the costs of the production of bioethanol on the basis of ligno-cellulose biomass in Switzerland. Borregard Schweiz AG is the biggest producer of ethanol in Switzerland with a yearly production of 11 million litres ethanol. It plans a new plant that will produce bioethanol out of ligno-cellulose by 2010. The costs of the production of bioethanol is divided in feedstock transport costs (14%), feedstock non-transport costs (30%), investment costs (43%), fixed operating costs (9%), variable operating costs (4%). The total price in 2010 is estimated to be 1.46 CHF/l (comparison: conventional gasoline would be 1.37 CHF/l), in 2025 1.15 CHF/l (conventional gasoline 1.87 CHF/l). The results depend of course on assumptions on the development of the price of conventional gasoline.

BFE/EWG (2004) also studies the costs of production of bio-diesel from Fischer-Tropsch process. The costs (assuming that bio-diesel is exempted from taxes) are 0.15 CHF/kWh in 2010 (conventional diesel: 0.14 CHF/kWh), in 2025 also 0.15 CHF/kWh, conventional diesel however being more expensive (about 0.20 CHF/kWh). The authors also calculate the costs in CHF/km for a VW Golf Trendline using bio-diesel in 2010 (about 0.54 CHF/km).

The authors of BFE/EWG (2004) conclude that at present ethanol is far from being competitive with gasoline. The tax on alcohol would need to be reduced compared to gasoline so as to allow bioethanol to be competitive on the vehicle fuel market. They also conclude that Fischer-Tropsch technology using biomass as a feedstock may become a competitive option.[6] It is however depending on the condition that the costs of biomass should be decreasing below its actual projection (4 cts/kWh). A major constraint for the implementation of biomass-based FT process in industrial scale would be the competition of biomass resource with other biomass energy technologies which may turn out to be less capital intensive and offer lower production costs in short to medium term. A detailed assessment of future availability and cost of biomass is necessary for an economic assessment of the FT-biofuels technology.

[6] See e.g. www.choren.de for information on the Choren-process for producing BTL-fuel.

1.3.9 Restrictions (policies and markets)

The Swiss agricultural policy defines the current goals, which are to maintain a multifunctional agriculture with food production. It can be assumed therefore that grassland will be mostly used for animal production also in the future and that the energy production with biomass will stay marginal.

BFE/EWG (2004) sees the most relevant developments in the biomass use for energy goals in the production of heat from wood furnaces and of electricity from biomass in wood gasification and biogas plants. In 2000 the confederation stopped to subsidize wood furnaces. Now only a few cantons are granting subsidies for this kind of heating system. The confederation encourages the production of electricity from biomass. However, the plant operator has to deliver the electricity produced through the electrical power supplier.

The use of forest area is ruled by the “forest law” in Switzerland (Schweizerisches Waldgesetz), which defines the sustainable use of the Swiss forests. The total forest area is protected. Wood wastes from wood industry are already used as a raw material in other industries. In the future a competitive situation will occur between use in energy production and in material recycling.

The development of the production of biofuels has many constraints: the technology is not yet mature and the potential of biomass production in Switzerland for this application has not been studied yet. As the agriculture area isn't sufficient for the food production for the whole population and as food imports are already necessary, it cannot be expected that big areas in Switzerland can be used for energy crops like miscanthus. Forest area is however increasing, mostly in the Alpine regions.

The Swiss government plans a revision of the tax law on mineral oil. Important for further development of biofuels market in Switzerland is the foreseen tax exemption for biofuels, which would become effective on the 1.1.2007. In the same time the tax on fossil fuels would be raised, so that demand for biofuels should increase[7].

1.3.10 Import of biomass and biofuels

At the moment there is an ongoing discussion in Switzerland about the opening of the market for the importation of biofuels. Tab. 1.3 shows the major types of biofuels that might be imported to Switzerland in the near future.

Tab. 1.3 Possible bioenergy products that might be imported to Switzerland and their origin country

Product	Countries
Biogas	Imports improbable
Methanol	Imports improbable
RME	DE, FR, AT, IT
Biogenic waste oil	DE, FR, AT, IT
BTL	Only large-scale production makes sense. Thus imports are probable, but countries cannot be identified yet.
Ethanol, from sugar cane	BR (60% of today world production), IN, CN
Ethanol, from corn	US (40% of today world production), CN
Ethanol, from sweet sorghum	CN
ETBE	DE
Palm oil methyl ester	South and Central America, eg. BR, South-East Asia, e.g. Indonesia

[7] see also http://www.zoll.admin.ch/d/gesetze/minoestgesetz/minoestgesetz.php

1.3.11 Summary

In Switzerland the distribution of biomass potential shows that forestry residues and wood industry by-products dominate with over 70% due to the high share of forestry in the country and the high rate of wood felling. However, forestry residues and wood by-products are currently used for energy production and in the wood processing industry. Thus only a limited market surplus is expected. There are no significant surpluses of agriculture residues. An overall increase in the use of biofuels in Switzerland is therefore only possible with the import of bioenergy products.

1.4 Characterisation of materials, energy carriers and products

The characterisation of the different products and energy carriers investigated in this project can be found in the individual chapters of part II in this report. It includes a clear characterisation of the products or fuels concerning the elemental analysis, heating value and density.

2 General methodology

The methodology for the investigation of life cycle inventory data of different unit processes has been described in detail in the methodology report of the ecoinvent project (Frischknecht et al. 2007a) and was used in this study. Thus, all unit processes are compatible with the ecoinvent datasets. For readers, who are not familiar with this methodology, it is recommended to read the methodology report before working with the unit process datasets shown in this report.

For single unit processes of this project the specific methodology for similar processes has been used. For instance, the investigation of agricultural products follows the guidelines of (Nemecek et al. 2007), the investigation of chemicals (Althaus et al. 2007a), the investigation of transport services (Spielmann et al. 2007). Biogas distribution was assessed using data from (Faist Emmenegger et al. 2003).

The following sections describe only some common conventions that are of specific relevance for the systematic investigation of bioenergy fuels, products and services in this project.

Specific methodological aspects for single unit processes are described in the subsequent chapters of part II in this report.

2.1 Time frame of the investigation

This project started in late 2004. All datasets should describe as far as possible the supply situation in Switzerland in the year 2004. This time frame is in contrast to reference year 2000 that has been chosen for the unit process datasets in ecoinvent data v1.2. Many of the processes investigated for bioenergy are emerging technologies. For a fair comparison with existing technologies it is important to consider the technological status and environmental impacts for plants working under real market conditions. Thus the most recent reference year has been chosen. If specific products are not yet introduced to the market, an assumption is made for the situation after the introduction to the market.

2.2 Plant size and assessment for emerging technologies

If plants only exist on a laboratory or pilot scale, assumptions are taken for a future scenario with a realistic plant size for a production in Switzerland. Therefore data from other countries or from small-scale plants have been used in this case. All assumptions and possible variations are documented in the EcoSpold format and in the report. Uncertainties due to such scenarios are considered in the calculation of the standard deviation.

2.3 Infrastructure for conversion processes

Data of the infrastructure of bioenergy conversion processes are rarely available. If no information is available, a rough assumption with the dataset developed for “facilities, chemical production” is used (Althaus et al. 2007a). This process is used with a standard input of 4.0 E-11 unit/kg and includes the dismantling of the plant. The pedigree matrix with (4,5,na,na,na,na) is used to determine the uncertainty for this rough estimation.

The lifetime of infrastructure of conversion processes is estimated with 50 years as a default value if specific information is not available. For the construction time 2 years are assumed.

2.4 Transports of biomass to the conversion plant

The transport distance of biomass from the point of harvest or formation to the conversion plant depends on the actual capacity of the plant and the potential of the necessary biomass resources in the surrounding area. This information is often not available. As a standard distance for the delivery of biomass from the field or the farm to the conversion plant 100 km with a “transport, lorry of 16t/CH” is used.

Swiss transport data sets are always used if the transport takes place in Switzerland.

2.5 Allocation for by-products

In several production processes for biomass fuels there are by-products. These by-products can be used for example as fodder or as a building material. In many cases it is not possible to avoid an allocation decisions because not sufficient data were available to give physical relationships for all inputs and outputs.

In general the market price of the different products has been used as an allocation criterion if no better information was available. The energy content of the products has normally not been used to derive allocation factors. Further details can be found in the detailed description of the datasets.

Tab. 2.1 Prices of several products used for economic allocation in this study

		CH	Brasil
product		price	price
		CHF	R$
biogas	kWh	0.04	
electricity, ethanol	kWh	0.10	57.5
electricity, waste incineration	kWh	0.073	
heat, waste incineration	MJ	0.09	
ethanol, 95% wt.	l	1.30	0.72
ethanol, 99.7% wt.	l	1.40	0.82
bagasse			0.04

2.6 Fuel at regional storage

Inventory data of the regional storage of liquid biofuels are consistent with the inventory data of petrol and diesel fuels (Jungbluth 2007:174). This unit process includes all transports from the processing to the filling station, the infrastructure of intermediate tanks and the filling station, fugitive emissions to air during refilling and storage operations, water emissions from run of water at the filling station.

The following standard assumptions are used if data are not available:

- 0.5 g/kg fuel are assumed as losses to air. The fugitive emissions to air have to be adapted to the fuel properties.
- Transport of fuel to the filling station is 150 km with lorry 28 t and 100 km with freight train.
- Data of electricity use, infrastructure, water use and emissions are based on the inventory of petrol (see Tab. 2.2)

If fuels are imported to Switzerland to a certain share, these transports are considered additionally.

The standard product quality for all datasets investigated for 2005 is low-sulphur diesel or petrol.

Tab. 2.2 Life cycle inventory data of fuel distribution in this project based on ecoinvent data v1.2

	Name	Location	InfrastructureProc	Unit	petrol, unleaded, at regional storage	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				kg			
product	petrol, unleaded, at regional storage	CH	0	kg	1			
technosphere	petrol, unleaded, at refinery	CH	0	kg	1.00E+0	1	1.05	(1,1,1,1,1,1); Product plus losses
	electricity, low voltage, at grid	CH	0	kWh	6.70E-3	1	1.25	(2,4,1,3,3,3); Data for fuel distribution (storage and filling station)
	light fuel oil, burned in boiler 100kW, non-modulating	CH	0	MJ	6.21E-4	1	1.25	(2,4,1,3,3,3); Data for fuel distribution (storage)
	tap water, at user	CH	0	kg	6.89E-4	1	1.25	(2,4,1,3,3,3); Data for petrol distribution
	transport, lorry 28t	CH	0	tkm	1.50E-1	1	2.09	(4,5,na,na,na,na); Standard assumption 150km from plant to filling station
	transport, freight, rail	CH	0	tkm	1.00E-1	1	2.09	(4,5,na,na,na,na); Standard assumption 100km from plant to filling station
	transport, freight, rail	RER	0	tkm		1	2.00	(,,,,,); Import of products
	transport, barge tanker	RER	0	tkm		1	2.00	(,,,,,); Import of products
	transport, crude oil pipeline, onshore	RER	0	tkm		1	1.05	(,,,,,); Import of products
	regional distribution, oil products	RER	1	unit	2.78E-10	1	3.06	(3,na,1,3,3,na); Average data for petrol station
	treatment, sewage, to wastewater treatment, class 2	CH	0	m3	6.89E-7	1	1.25	(2,4,1,3,3,3); Used water
	treatment, rainwater mineral oil storage, to wastewater treatment, class 2	CH	0	m3	7.50E-5	1	1.40	(4,5,3,3,3,na); Treatment of rainwater with pollutants
	disposal, municipal solid waste, 22.9% water, to sanitary landfill	CH	0	kg	6.27E-6	1	1.25	(2,4,1,3,3,3); Environmental report for wastes
	disposal, separator sludge, 90% water, to hazardous waste incineration	CH	0	kg	1.68E-4	1	1.27	(2,4,3,3,3,3); Sludge from storage, environmental report and literature
emission air, high population density	Heat, waste	-	-	MJ	2.41E-2	1	1.14	(2,4,1,3,1,3); Calculation with electricity use
	Benzene	-	-	kg		1	1.70	(4,5,2,5,3,4); Losses 0.05% according to product properties
	Benzene, ethyl-	-	-	kg		1	1.70	(4,5,2,5,3,4); Losses 0.05% according to product properties
	Hexane	-	-	kg		1	1.70	(4,5,2,5,3,4); Losses 0.05% according to product properties
	Hydrocarbons, aliphatic, alkanes, unspecified	-	-	kg		1	1.70	(4,5,2,5,3,4); Losses 0.05% according to product properties
	Hydrocarbons, aliphatic, unsaturated	-	-	kg		1	1.70	(4,5,2,5,3,4); Losses 0.05% according to product properties
	Hydrocarbons, aromatic	-	-	kg		1	1.70	(4,5,2,5,3,4); Losses 0.05% according to product properties
	Methane, fossil	-	-	kg		1	1.70	(4,5,2,5,3,4); Losses 0.05% according to product properties
	t-Butyl methyl ether	-	-	kg		1	1.70	(4,5,2,5,3,4); Losses 0.05% according to product properties
	Toluene	-	-	kg		1	1.70	(4,5,2,5,3,4); Losses 0.05% according to product properties

2.7 Energy resources

The demand for biogenic energy resources is considered for all agricultural and forestry products with an input of "Energy, gross calorific value, in biomass" at the first stage of production.

This flow is not included in the investigation of secondary resources, by-products and wastes that do not bear any burdens from the upstream processes or the first life cycle. Thus, products from such biomass resources do not bear the burden of a direct use of biogenic energy resource.[8] Their actual demand for energy resources might be therefore lower than their actual energy content. This is consistent with other inventories, e.g. of cement where energy inputs from secondary resources such as waste types are not accounted for.

2.8 Reference unit of products

If not stated otherwise all information on gases is referred to the standard unit "cubic metre at normal conditions" or Nm^3. Normal conditions are a temperature of 273.15 K or 0°C and a pressure of P= 1.01325 10E5 Pa. The according volume is V_{molar} = 0.022414 m^3/mol.

Please note that Nm^3 might mean different standard conditions depending on the standard used, e.g. T = 0°C = 273,15 K (DIN 1343) or T = 15°C (ISO 2533)[9]!

Some inventories for chemicals are investigated for the mass of pure chemical with a given degree of purity. Thus "ethanol, 95% in H2O, from whey, at fermentation plant" means on kilogram of pure ethanol with a purity of 95% mass percent (plus 0.053 kg of water). Thus in total the datasets refers to 1.053 kg of ethanol 95% in water. This total weight has to be considered in the calculations for transport processes.

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[8] This is not consistent e.g. with the Swiss energy statistics where energy from waste is accounted for (BFE 2000).

[9] http://normkubikmeter.lexikon.fluessiggas.net/

2.9 Biogenic carbon balance

So far different solutions have been used in the ecoinvent database to allocate the biogenic carbon content and biogenic CO2- emissions to different products with a low or unknown economic value (Doka 2007; Nemecek et al. 2007; Werner et al. 2007). Common for most of these solutions is the maintenance of a correct carbon balance even if other elementary flows are allocated according to economic properties. For agricultural products the allocation factors have been calculated according to the carbon content of the allocated co-products. For wood products a virtual allocation correction process has been introduced in order to correct the carbon balance for products with a low economic value.

With the start of the bioenergy project these different approaches have been analysed. The approach used in the bioenergy project is based on most of the models used in ecoinvent data v1.2. It has the following basic principles for all types of processes and products:

- For each product and process the biogenic and fossil C-content is reported and calculated correctly.
- For each process all functions (products and services) are taken into account. There are no hidden zero allocations to certain products or services with low or no economic value. The user can change allocation factors e.g. for changes in the revenue structure.
- For several intermediate products of the modelling prices are not available or might be quite unsure. The resulting C-balance has been modelled in all cases according to the defined product properties. There are no inconsistencies due to close to zero prices. Thus no escalating change of the C-balance can be observed if the price changes from nearby zero to zero due to the use of a cut-off approach.
- The approach fully avoids the modelling of virtual processes, which are so used only for wood products in order to maintain a correct carbon balance for products with no or low economic value (Werner et al. 2007).

A correct carbon balance should be maintained for all unit processes in the database. This means:

Input of carbon = Output of carbon

This means that the uptake of carbon during plant growing (carbon dioxide, in air) plus all inputs of biogenic carbon with pre-products minus biogenic carbon emissions (e.g. CO_2, CH_4 and CO) should equal the biogenic carbon content of the biofuel or the product after all calculations and allocations have been done. Thus the following equatation is given for each unit or multi-output process:

$$C_{in,resource} + C_{in,pre\text{-}product} = C_{out,\ emissions} + C_{out,\ process\text{-}output}$$

$C_{in,resource}$ = Carbon dioxide, in air (EcoSpold InputGroup = 4)

$C_{in,pre\text{-}product}$ = all biogenic carbon content of inputs with technosphere processes (InputGroup = 5)

$C_{out,\ emissions}$ = carbon content of biogenic air emissions of CO_2, CH_4, CO, NMVOC and carbon emissions to water (e.g. TOC) (OutputGroup = 4)[10]

$C_{out,\ process\text{-}output}$ = carbon content of outputs with technosphere processes, (OutputGroup = 0 or 2)

[10] Biogenic carbon emissions others than CO_2, CH_4 and CO are disregarded in some cases were the CO_2-emission is based on pure mathematical calculation. Normally the influence of such deviation for the results is quite small.

Three different types of unit process outputs (products and services) can be distinguished:

1.) Electricity, heat, transport services, etc.

$C_{out,\ process\text{-}output} = 0$ (There is no material output with a C-content from such processes).

➔ $C_{in,resource} + C_{in,pre\text{-}product} = C_{out,\ emissions}$

2.) Materials, fuels, etc.

$C_{out,\ process\text{-}output} > 0$ (the C-content is equal the carbon actually bound in the product)

➔ $C_{in,resource} + C_{in,pre\text{-}product} = C_{out,\ emissions} + C_{out,\ process\text{-}output}$

3.) Waste treatment services. Waste treatment services do not have a direct link to the production of the treated product. The emissions during waste treatment should equal the carbon content of the product that is brought to waste treatment. If the same amount of the product and the waste treatment service is used in a process the resulting carbon balance should be zero. Thus the following equatation is true:

C-content(product to be treated, but not part of the unit process) + $C_{out,\ process\text{-}output} = 0$

➔ $C_{out,\ process\text{-}output} = -$ C-content(product to be treated)

➔ $C_{out,\ emissions} - C_{in,resource} - C_{in,pre\text{-}product} =$ C-content(product to be treated)

In most cases with $C_{in,resource} = C_{in,pre\text{-}product} = 0$

➔ $C_{out,\ emissions} =$ C-content(product to be treated) $= - C_{out,\ process\text{-}output}$

4.) A combination of different types of basic processes in one multi-output processes is possible. In this case the according equatation have to be fulfilled for each allocated product. The total for the multi-output process should equal the sum of the correct balances for the single outputs (services and products).

The input and output flows of biomass carbon are discussed for the individual process stages. The carbon content of all products and by-products is stated in order to follow up this balance.

Biogenic NMVOC emissions to air and carbon emissions to water (TOC – Total Organic Carbon) are not considered in the balance, if the CO_2 emission is calculated with fuel properties, because they are neither accounted for in the calculations for the climate change effects in the LCIA.[11]

The uptake of "Carbon dioxide, in air" is inventoried for all agricultural and forestry products at the beginning of the life cycle. This flow is also included in the inventory of secondary resources and by-products at the first stage of conversion to a biofuel. Due to budget restriction it was not possible to inventory the full first life cycle of such by-products, e.g. whey from milk processing (see Fig. 2.1).

The economic value of such by-products and secondary resources is not often not known. They do normally have a low or no economic value. All economic inputs from the first life cycle are thus allocated to the main products (in this case milk, for example). Thus, for the production of such biogenic wastes all inputs from the first life cycle can be neglected with the only exception of the carbon uptake during plant growing. For these biofuels the input of carbon dioxide at the beginning of their life cycle equals the emissions during conversion and combustion. This is necessary in order to achieve a neutral

[11] This is in line with the approach taken for combustion processes using fossil fuels were the CO_2 emissions is also calculated from the carbon content of the fuel.

carbon balance while assessing environmental impacts according to the old implementation rules for greenhouse gas emissions in the database (Frischknecht et al. 2004). With the new implementation without accounting for biogenic CO_2 uptake and emissions this is normally not an issue (Frischknecht et al. 2007b)

For most of the unit processes it was necessary to use calculated CO_2 emissions (instead of measurements), a calculated input of the biomass, the biofuel input or the carbon resource in order to achieve a correct carbon balance. In contrast other emissions like CO, CH_4 and NMVOC are based on measurements.

For multi-output processes it was necessary to adapt the allocation factors for CO_2, biomass or biofuel input in order to achieve a correct balancing. Thus these factors might deviate from the factors used for all other input and output flows.

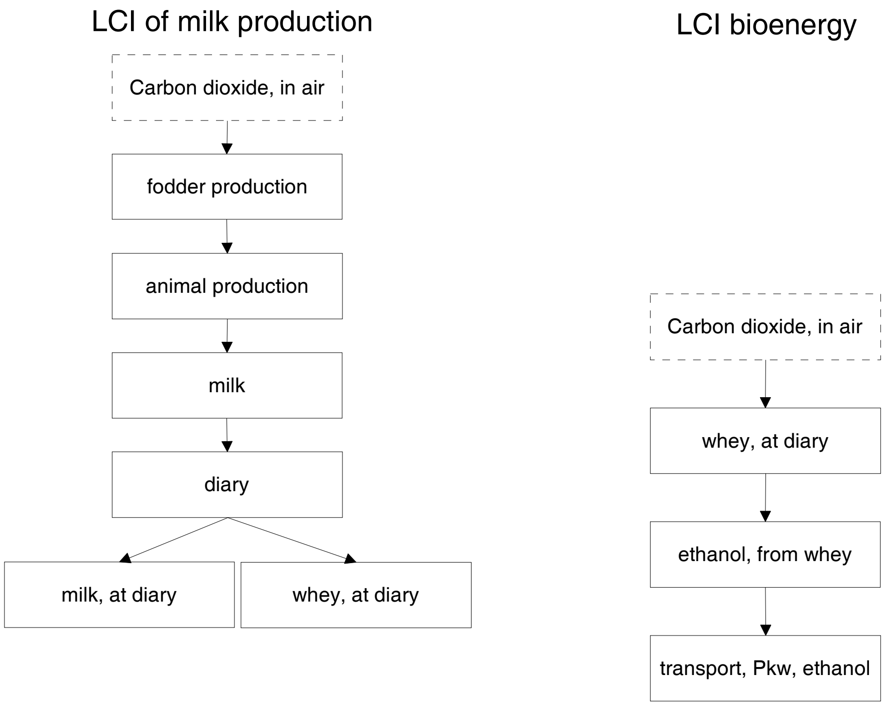

Fig. 2.1 Example for estimating a correct carbon balance for by-products with no economic value coming from a life cycle not investigated so far in the database

Tab. 2.3 shows a fictive example for the calculation of a correct carbon balance in a unit process with different inputs and outputs. The columns M and N show the inputs and outputs with each elementary flow while in the last three rows there is a calculation for the total balance. Carbon dioxide emissions are calculated as the balance of other inputs and outputs.

Tab. 2.3 Fictive example for the calculation of a correct carbon balance in a normal unit process

	B	D	E	F	G	J	K	L	M	N
3	Explanations	Input-Group	Output-Group	Name	Location	Infrastructure-Process	Unit	ethanol, 95% in H2O, from grass, at fermentation plant	biogenic carbon content in elementary flow	biogenic carbon balance
4				Location				CH		
5				InfrastructureProcess				0		
6				Unit				kg	kg	kg
7	Technosphere	5		grass from meadow intensive IP, at field	CH	0	kg	5.0E-1	0.45	0.225
8		5		grass from natural meadow intensive IP, at field	CH	0	kg	1.0E+0	0.45	0.450
9		5		grass from natural meadow extensive organic, at field	CH	0	kg	1.0E+0	0.45	0.450
10		5		transport, lorry 16t	CH	0	tkm	1.0E-1	-	-
11		5		electricity, medium voltage, at grid	CH	0	kWh	4.6E-2	-	-
12		5		heat, unspecific, in chemical plant	RER	0	MJ	6.0E-1	-	-
13		5		ethanol fermentation plant	CH	1	unit	1.4E-11	-	-
14			4	Carbon dioxide, biogenic			kg	2.1E+0	*0.27*	*0.563*
15			4	Carbon monoxide, biogenic			kg	1.0E-2	0.43	0.004
16			4	Methane, biogenic			kg	5.0E-2	0.75	0.038
17			4	Heat, waste			MJ	1.6E-1	-	-
18	Outputs		0	ethanol, 95% in H2O, from grass, at fermentation plant	CH	0	kg	1.0E+0	0.52	0.520
19										
20	Calculation			$C_{in,pre\text{-}product}$			kg			1.125
21				$C_{out,\ emissions}$			kg			0.042
22				$C_{out,\ process\text{-}output}$			kg			0.520
23				$C_{out,\ emissions,\ CO2}$ (calculated)			kg			0.563
24				Input - Output			kg			-

The following table shows a fictive example for the calculation of a correct carbon balance in a multi-output process with different inputs and outputs. The columns S and T show the inputs and outputs with each elementary flow while in the last three rows there is a calculation for the total balance. Total carbon dioxide emissions are calculated as the balance of other inputs and outputs. Allocation factors for carbon dioxide, biogenic are based on a correct input-output balance for the three couple products.

Tab. 2.4 Fictive example for the calculation of a correct carbon balance in a multi-output process

	B	D	E	F	G	J	K	L	P	Q	R	S	T
3	Explanations	Input-Group	Output-Group	Name	Location	Infrastructure-Process	Unit	grass , to fermentation	ethanol, 95% in H2O, from grass, at fermentation plant	grass fibres, at fermentation	proteins from grass, at fermentation	biogenic carbon content in elementary flow	biogenic carbon balance
4				Location				CH	CH	CH	CH		
5				InfrastructureProcess				0	0	0	0		
6				Unit				kg	kg	kg	kg	kg	kg
7	Inputs	5		grass from meadow intensive IP, at field	CH	0	kg	3.2E-1	20.0	45.0	35.0	0.45	0.146
8		5		grass from natural meadow intensive IP, at field	CH	0	kg	6.2E-1	20.0	45.0	35.0	0.45	0.277
9		5		grass from natural meadow extensive organic, at field	CH	0	kg	6.1E-2	20.0	45.0	35.0	0.45	0.027
10	Technosphere	5		transport, lorry 16t	CH	0	tkm	1.0E-1	20.0	45.0	35.0	-	-
11		5		electricity, medium voltage, at grid	CH	0	kWh	4.6E-2	20.0	45.0	35.0	-	-
12		5		heat, unspecific, in chemical plant	RER	0	MJ	6.0E-1	20.0	45.0	35.0	-	-
13		5		ethanol fermentation plant	CH	1	unit	1.4E-11	20.0	45.0	35.0	-	-
14	air, high population density		4	Carbon dioxide, biogenic			kg	1.3E+0	19.4	46.9	33.7	*0.27*	*0.354*
15			4	Carbon monoxide, biogenic			kg	1.0E-2	20.0	45.0	35.0	0.43	0.004
16			4	Methane, biogenic			kg	5.0E-2	20.0	45.0	35.0	0.75	0.038
17			4	Heat, waste			MJ	1.6E-1	20.0	45.0	35.0	-	-
18	Outputs		2	ethanol, 95% in H2O, from grass, at fermentation plant	CH	0	kg	2.5E-2	100.0			0.52	0.013
19			2	grass fibres, at fermentation	CH	0	kg	4.0E-2		100.0		0.45	0.018
20			2	proteins from grass, at fermentation	CH	0	kg	5.2E-2			100.0	0.45	0.024
21													
22	Calculation for biogenic carbon			$C_{in,pre\text{-}product}$			kg	2.2E-3	9.0E-2	2.0E-1	1.6E-1		0.450
23				$C_{out,\ emissions}$			kg	1.9E-5	8.4E-3	1.9E-2	1.5E-2		0.042
24				$C_{out,\ process\text{-}output}$			kg	2.3E-5	1.3E-2	1.8E-2	2.4E-2		0.055
25				$C_{out,\ emissions,\ CO2}$ (calculated)			kg	2.1E-3	6.8E-2	1.7E-1	1.2E-1		0.354
26				Input - Output			kg	-	-	-	-		-

Even with these refined calculation procedures some small deviations from a fully correct carbon balance are possible e.g. due to rounding errors or neglecting of water pollutants in the balance. Such deviations are tolerated if they amount to less than about 1 $^0/_{00}$ of the carbon flow with the production process.

2.10 Inventories for felling of primary forests

2.10.1 Introduction

Several aspects of carbon modelling have to be considered for the unsustainable use or deforestation of primary tropical forests and its following transformation to agricultural or forestry land.

Due to the initial felling, carbon dioxide is released from burning or degradation of unused biomass. Later on carbon dioxide bound in the wood is released after its use. Thus it should be considered as a CO_2- release.

A second source of CO_2-emissions is the release of carbon bound in the soil. This is degraded after the transformation i.e. to agricultural land.

These emissions and resource uses need to be allocated between the initial production of wood from the forest and subsequent transformation to agricultural land.

The felling of primary forests might also reduce methane and other emission occurring naturally (Lowe 2006). Such reductions of emissions occurring prior to the process of interest are generally not accounted for according to the ecoinvent methodology.

A change of carbon content in soils or organic matter above ground occurs also for all other types of land transformation, e.g. transformation from meadow to arable land. So far these changes have not been considered in ecoinvent data. They are normally of much less importance than the transformation of primary forests to arable land. Thus, they are also not taken into account for the inventories elaborated in this report.

2.10.2 Methodology

The inventory modelling starts with the first felling action. The uptake of CO_2 does not take place within the temporal system boundaries of the process. The uptake already took place before the first actions like building of streets or felling have been started. Thus, the existing elementary flow "Carbon dioxide, in air" is not inventoried for the carbon contents of wood and soil.

For analytical reasons it is favourable to record the non-renewable carbon bound in wood and soil with new elementary flows. Also the energy content of the wood from the primary forest is recorded with a separate elementary flow. Thus it is possible to make latter on detailed analysis with the data. The following two new elementary flows are used for the extraction of wood and for the degradation of carbon bound in soil:

Wood, primary forest, standing
Carbon, in organic matter, in soil
Energy, gross calorific value, in biomass, primary forest

All CO_2 emissions due to land transformation from wood burning and degradation of carbon bound in soil are recorded with a new type of emissions. The basic uncertainty for this elementary flow is estimated to be relative high (1.4). The separate elementary flow makes it possible to calculate different scenarios for the impact assessment of these specific type of emissions.

Carbon dioxide, land transformation

For transformation for tropical forest to agricultural land the changes for the reference plantation period are recorded. The full land transformation is allocated to the use of land for agriculture. This is the same methodological approach as used for other agricultural products (Nemecek et al. 2007). Land transformation and occupation are recorded according to existing guidelines with new elementary flows:

Occupation, tropical rain forest
Transformation, from tropical rain forest
Transformation, to tropical rain forest

The emissions must be allocated among first initial felling with the production of wood and the following use as agricultural or forestry land. Therefore a multi-output dataset is inventoried. First, the land is transformed to "forest, clear-cutting". If no better information is available all carbon dioxide releases from burning of wood and degradation of carbon content bound in soil are allocated to the use of the land for agriculture or forestry.

The further details are elaborated in the inventory analysis of such processes.

2.11 New elementary flows

The following new elementary flows have been used in the database. All LCIA methods have to be complemented by the users of the datasets investigated in this project.

Tab. 2.5 New elementary flow for resources used for this project

Name	Category	SubCategory	Formula	Unit	CAS
Occupation, tropical rain forest	resource	land	CORINE not known	m2a	
Transformation, from tropical rain forest	resource	land	CORINE not known	m2	
Transformation, to tropical rain forest	resource	land	CORINE not known	m2	
Wood, primary forest, standing	resource	biotic		m3	
Carbon, in organic matter, in soil	resource	in ground	C	kg	007440-44-0
Energy, gross calorific value, in biomass, primary forest	resource	biotic		MJ	

Tab. 2.6 New elementary flow for emissions to agricultural soil used for this project

Name	Category	SubCategory	Formula	Unit	CAS
Aldrin	soil	agricultural	C12H8Cl6	kg	000309-00-2
Acetamide	soil	agricultural	CH3CONH2	kg	000060-35-5
Acetochlor	soil	agricultural	C14H20ClNO2	kg	034256-82-1
Alachlor	soil	agricultural	C14H20ClNO2	kg	015972-60-8
Azoxystrobin	soil	agricultural	C22H17N3O5	kg	131860-33-8
Benomyl	soil	agricultural	C14H18N4O3	kg	017804-35-2
Carbufuran	soil	agricultural	C12H15NO3	kg	001563-66-2
Chlorimuron-ethyl	soil	agricultural	C15H15ClN4O6S	kg	090982-32-4
Cinidon-Ethyl	soil	agricultural	C19H17Cl2NO4	kg	142891-20-1
Clethodim	soil	agricultural	C17H26ClNO3S	kg	099129-21-2
Cloransulam-methyl	soil	agricultural	C15H13ClFN5O5S	kg	147150-35-4
Cyfluthrin	soil	agricultural	C22H18Cl2FNO3	kg	068359-37-5
Dichlorprop-P	soil	agricultural	C9H8Cl2O3	kg	015165-67-0
Diflubensuron	soil	agricultural	C14H9ClF2N2O2	kg	035367-38-5
Diflufenzopyr-sodium	soil	agricultural	C15H11F2N4NaO3	kg	109293-98-3
Dimethachlor	soil	agricultural	C13H18ClNO2	kg	050563-36-5
Dimethoate	soil	agricultural	C5H12NO3PS2	kg	000060-51-5
Dithianon	soil	agricultural	C14H4N2O2S2	kg	003347-22-6
Endosulfan	soil	agricultural	C9H6Cl6O3S	kg	000115-29-7
Esfenvalerate	soil	agricultural	C25H22ClNO3	kg	066230-04-4
Fenbuconazol	soil	agricultural	C19H17ClN4	kg	114369-43-6
Fenoxaprop	soil	agricultural	C16H12ClNO5	kg	095617-09-7
Fipronil	soil	agricultural	C12H4Cl2F6N4OS	kg	120068-37-3
Flumetsulam	soil	agricultural	C12H9F2N5O2S	kg	098967-40-9
Flumioxazin	soil	agricultural	C19H15FN2O4	kg	103361-09-7
Fluquinconazole	soil	agricultural	C16H8Cl2FN5O	kg	136426-54-5
Flurtamone	soil	agricultural	C18H14F3NO2	kg	096525-23-4
Fomesafen	soil	agricultural	C15H10ClF3N2O6S	kg	072178-02-0
Foramsulfuron	soil	agricultural	C17H20N6O7S	kg	173159-57-4
Imazamox	soil	agricultural	C15H19N3O4	kg	114311-32-9
Imazapyr	soil	agricultural	C13H15N3O3	kg	081334-34-1
Imazethapyr	soil	agricultural	C15H19N3O3	kg	081335-77-5
Iodosulfuron	soil	agricultural	C13H12IN5O6S	kg	185119-76-0
Iprodion	soil	agricultural	C13H13Cl2N3O3	kg	036734-19-7
Isoxaflutole	soil	agricultural	C15H12F3NO4S	kg	141112-29-0
Kresoxim-methyl	soil	agricultural	C18H19NO4	kg	143390-89-0
Mefenpyr	soil	agricultural	C12H10Cl2N2O4	kg	135591-00-3
Mesotrione	soil	agricultural	C14H13NO7S	kg	104206-82-8
Monocrotophos	soil	agricultural	C7H14NO5P	kg	006923-22-4
Oxydemeton-methyl	soil	agricultural	C6H15O4PS2	kg	000301-12-2
Paraquat	soil	agricultural	C12H14N2	kg	004685-14-7
Parathion	soil	agricultural	C10H14NO5PS	kg	000056-38-2
Permethrin	soil	agricultural	C21H20Cl2O3	kg	052645-53-1
Primisulfuron	soil	agricultural	C14H10F4N4O7S	kg	113036-87-6
Prosulfuron	soil	agricultural	C15H16F3N5O4S	kg	094125-34-5
Quinmerac	soil	agricultural	C11H8ClNO2	kg	090717-03-6
Quizalofop-P	soil	agricultural	C17H13ClN2O4	kg	094051-08-8
Spiroxamine	soil	agricultural	C18H35NO2	kg	118134-30-8
Sulfentrazone	soil	agricultural	C11H10Cl2F2N4O3	kg	122836-35-5
Sulfosate	soil	agricultural	C6H16NO5PS	kg	081591-81-3
tau-Fluvalinate	soil	agricultural	C26H22ClF3N2O3	kg	102851-06-9
Tebupirimphos	soil	agricultural	C13H23N2O3PS	kg	096182-53-5
Tefluthrin	soil	agricultural	C17H14ClF7O2	kg	079538-32-2
Thiophanat-methyl	soil	agricultural	C12H14N4O4S2	kg	023564-05-8
Thiram	soil	agricultural	C6H12N2S4	kg	000137-26-8
Triadimenol	soil	agricultural	C14H18ClN3O2	kg	055219-65-3
Tribenuron	soil	agricultural	C14H15N5O6S	kg	106040-48-6
Vinclozolin	soil	agricultural	C12H9Cl2NO3	kg	050471-44-8

Tab. 2.7 New elementary flow for emissions to air used for this project

Name	Category	SubCategory	Formula	Unit	CAS
Carbon dioxide, land transformation	air	high population density	CO2	kg	000124-38-9
Carbon dioxide, land transformation	air	low population density	CO2	kg	000124-38-9
Carbon dioxide, land transformation	air	low population density, long-term	CO2	kg	000124-38-9
Carbon dioxide, land transformation	air	lower stratosphere + upper troposphere	CO2	kg	000124-38-9
Carbon dioxide, land transformation	air	unspecified	CO2	kg	000124-38-9
Isoprene	air	high population density	C5H8	kg	000078-79-5
Isoprene	air	low population density	C5H8	kg	000078-79-5
Isoprene	air	low population density, long-term	C5H8	kg	000078-79-5
Isoprene	air	lower stratosphere + upper troposphere	C5H8	kg	000078-79-5
Isoprene	air	unspecified	C5H8	kg	000078-79-5
Terpenes	air	high population density	C10H16	kg	068956-56-9
Terpenes	air	low population density	C10H16	kg	068956-56-9
Terpenes	air	low population density, long-term	C10H16	kg	068956-56-9
Terpenes	air	lower stratosphere + upper troposphere	C10H16	kg	068956-56-9
Terpenes	air	unspecified	C10H16	kg	068956-56-9
Formic acid	air	high population density	CH2O2	kg	000064-18-6
Formic acid	air	low population density	CH2O2	kg	000064-18-6
Formic acid	air	low population density, long-term	CH2O2	kg	000064-18-6
Formic acid	air	lower stratosphere + upper troposphere	CH2O2	kg	000064-18-6
Formic acid	air	unspecified	CH2O2	kg	000064-18-6
Furan	air	high population density	C4H4O	kg	000110-00-9
Furan	air	low population density	C4H4O	kg	000110-00-9
Furan	air	low population density, long-term	C4H4O	kg	000110-00-9
Furan	air	lower stratosphere + upper troposphere	C4H4O	kg	000110-00-9
Furan	air	unspecified	C4H4O	kg	000110-00-9
Acetonitrile	air	high population density	C2H3N	kg	000075-05-8
Acetonitrile	air	low population density	C2H3N	kg	000075-05-8
Acetonitrile	air	low population density, long-term	C2H3N	kg	000075-05-8
Acetonitrile	air	lower stratosphere + upper troposphere	C2H3N	kg	000075-05-8
Acetonitrile	air	unspecified	C2H3N	kg	000075-05-8

2.12 Air emissions

Generally the sub-category “high population density” is used for all emissions to air from conversion processes. For other types of processes the same rules as for similar processes in ecoinvent data v1.2 are applied.

Emissions of sulphur dioxide are based on the sulphur content of the fuel.

Abbreviations

For abbreviations of country codes e.g. DE, FR, AT, IT, BR, IN, CN see the names list of the ecoinvent project.

BTL	biomass-to-liquid Treibstoff
DM	dry matter
DME	Dimethylether
dt	Dezitonnen (=100kg)
E-1	Exponential writing of figures. The information 1.2E-2 has to be read as 1.2 * 10-2 = 0.012.
ETBE	ethyl-tertiary-butyl-ether
IP	Integrated production (specific type of agricultural production in Switzerland)
LCA	life cycle assessment
LCI	life cycle inventory analysis
LCIA	life cycle impact assessment
m. o. s.	meter over sea level
Mm3	Million cubic metre

Nm^3	Norm cubic metre, volume of gases under norm conditions with temperature T = 0°C = 273,15 K (DIN 1343) **or!** T = 15°C (ISO 2533)[12] and pressure p = 101325 Pa = 101325 N/m² = 1013,25 hPa = 101,325 kPa. In this study we assume T = 0°C.
n.a.	not available
PJ	Peta Joule
RME	rape methyl ester
SME	sunflower methyl ester

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Part II

II. Life Cycle Inventories

Authors: see individual chapter

Citation:
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1 Introduction to Part II

The life cycle inventories of bioenergy have been investigated in three sub-projects by different project partners. The following chapters are included in this part of the report:

- i. Swiss agricultural products
  - Grass
  - Rape seed, organic
- ii. Foreign agricultural production
  - Corn, US
  - Oil palm, MY
  - Rape seed, conventional, DE
  - Rye conventional, RER
  - Soybean, BR and US
  - Sugar cane, BR
  - Sweet sorghum, CN
- iii. Biomass conversion to fuels
  - Biogas
    - Biowaste
    - Sewage sludge
    - Liquid manure
    - Agricultural co-digestion (plants without and with coverage for methane reduction)
    - Grass
    - Whey
  - Synthetic-fuels (Methane and Methanol from wood)
  - Ethanol 95% and 99.7%
    - Swiss biomass (sugar beets, grass, whey)
    - Sugar cane in Brazil
    - Swiss biomass (sugar beet molasses, potatoes, wood) and foreign production (rye, sugar-cane molasses, corn, sweet sorghum), ETBE production with ethanol from biomass (Ethyl Tert-butyl Ether)
  - Oil-based biofuels (rape seed, palm oil, soybeans, waste cooking oil)
  - Gaseous fuels at service station (biogas and natural gas)
- iv. Transport services
  - Road transport services biofuels and alternative fuels
  - Road transport services with recent emission standards[13]
- v. Waste management services

[13] These datasets have been investigated within this project, but they are documented in a separate ecoinvent report (Spielmann et al. 2007).

- Incineration of Biowaste and Sewage Sludge
- Incineration Sewage Sludge in Cement Kiln

- vi. Basic chemicals
  - Allyl chloride
  - Epichlorohydrin
  - Potassium hydroxide
  - n-Hexane
  - Synthetic glycerine
  - Allyl chloride from sieve separation of naphtha
  - Isobutene (not investigated)[14]

[14] Isobutylene or isobutene (CAS No. 000115-11-7) is a direct refinery product. Thus, it has not been investigated. Values for "naphtha, at refinery" are used as a proxy dataset. Personal communication between Mike Chudacoff and Michael Overcash, 18.2.2005.