Life Cycle Database for Bioenergy based on an Open Source IT-infrastructure

Schebek, L.1,*, Ciroth, A.2, Düpmeier, C.3, Eltrop, L.4, Simon, S.5, Viebahn, P.6, Wagner, H.-J.7 and Zschunke, T.8

*E-mail: liselotte.schebek@kit.edu

1Karlsruhe Institute for Technology (KIT), Institute for Technology Assessment and Systems Analysis, Department of Technology-Induced Material Flow (ITAS-ZTS), Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen

2GreenDeltaTC GmbH, Raumerstraße 7, 10437 Berlin

3Karlsruhe Institute for Technology (KIT), Institute for Applied Computer Science (IAI), Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen

4Universität Stuttgart, Institute of Energy Economics and the Rational Use of Energy (IER), Pfaffenwaldring 31, 70569 Stuttgart

5Wuppertal Institute for Climate, Environment, Energy GmbH, Research Group „Future Energy and Mobility Structures“, Döppersberg 19, 42103 Wuppertal

6German Aerospace Center, Institute of Technical Thermodynamics, Department for Systems Analysis and Technology Assessment, Pfaffenwaldring 38-40, 70569 Stuttgart

7Ruhr-Universität Bochum, LEE Energy Systems and Energy Economics Universitätsstraße 150, 44801 Bochum

8Hochschule Zittau/Görlitz, Faculty of Mechanical and Manufacturing Engineering, Theodor-Körner-Allee 16, 02763 Zittau

Abstract As part of the German funding program on energy-from-biomass, BioEnergieDat has been launched as a two-year’s project for a database on energetic use of biomass for Germany. The project will create a database to serve as basis within the German strategy on biomass; a modular design allows its use also for all applications of LCA and diverse related instruments like Carbon Footprint. The database is based on an Open Source IT-infrastructure to assure a most flexible access to data and tools developed for external users. Outline of the database concept is derived from an analysis of user needs of data sets. For storage, management and generation of the LCI datasets, an Open Source IT-infrastructure is established. A service-oriented application programming interface to the database provides quick access to shared data sets for the domain experts directly from within their tool environment.

1 Introduction

Life Cycle Assessment (LCA) has been amply used in recent years for studies on bioenergy. A large number of single studies as well as several comprehensive reviews exist, e.g. [1 – 4]. Based on these, data sets for life cycle inventory (LCI) of numerous process chains for bioenergy are available today. Methodological choices and factual specifications in studies are very diverse, however, resulting in discrepancies in quantitative assessment of identical technologies or products [4 - 6]. Although from the synopsis of studies a number of general insights on bioenergy can be derived unanimously, results may be too divergent if it comes to the assessment of specific technologies for decision support. In addition, information on novel technologies often is scarce, which makes an assessment unreliable.

As part of the German funding program on energy-from-biomass, a two-year's project for a database on energetic use of biomass for Germany has been launched by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) in September 2010. The project with the acronym BioEnergieDat is carried out by a consortium of seven scientific partners led by the Karlsruhe Institute of Technology (KIT). It is based on previous work and experiences of the German Netzwerk Lebenszyklusdaten (www.netzwerk-lebenszyklusdaten.de) and is aimed at a validated database for use within the German strategy on biomass, but also for all applications of LCA and diverse related instruments like Carbon Footprint. The database is derived based on a modular methodological approach and an Open Source IT-infrastructure consisting of a database and modeling software, to assure a most flexible access to data and tools developed within the project for external users.

2 Modular concept for provision of data sets

The BioEnergieDat database is based on a modular concept which is aimed to deliver data sets for full process chains of bioenergy from agriculture to supply of energy carriers or end energy, respectively. Each process within a process chain will be provided as a unit module data set which complies with the methodological and documentation framework to be developed during the project. In this manner, each unit process may be used independently for modeling purposes and process chains remain fully transparent; likewise quality assurance as well as a future up-dating may be performed on the level of each unit process, which ensures a high degree of flexibility and maximizes future use.

Data set generation in the project is based on a stepwise working process. In a first step, a comprehensive evaluation of literature and information on relevant bioenergy technologies is performed; main findings of this research are incorporated in the database as a kind of "technology fact sheet". In this way, a comprehensive assurance of data as well as a documentation of the origin of the information is performed. In addition, this information is helpful for a future evaluation, modification and continuous improvement of the data sets.

As a second step, a consistent framework for terminology, structure and content of data sets will be defined. In the project, these terms and expressions are compliant to DIN EN ISO 14040/14044 [7, 8], taking additional specifications as far as possible from the ELCD data base [9] and the Ecoinvent data base [10] and from other sources, e.g. [11-16].

In the third step, data sets will be created for all unit processes of the selected process chains. In the first working phase, 36 'conventional' bioenergy process chains of four technology lines (liquid first generation bio-fuels, biogas, heat and electricity generation, and biomass to liquid-BtL) are covered (table 1). A selection of the most important biomass raw materials of the technology lines were combined with the appropriate technologies to form bioenergy technology process chains with high relevance for the bioenergy sector in Germany

Tab.1: Selected biomass-technology combinations (process chains)

	rape	sun flower	potatoes	grain	sugar beet	fodder beet	maize whole plant	grass mixture	miscanthus	energy wood	straw	forest wood	cattle manure	pig manure	woody landscape	industry wood	sewage sludge	used wood (A I-	used edible fat
Plant Methylene Ether	X	X																	X
Plant oil	X	X																	X
Bio-Ethanol			X	X	X	X													
Bio-ETBE					X														
Biomass to Liquid BTL									X	X	X								
Pellet boiler 15 kW																X			
Heating plant 5 MW									X			X			X			X	
Biogas plant 250 kW				X			X	X					X	X			X		
Organic rankine cyle power plant										X		X			X				
Gasification CHP unit										X	X	X							
Steam turbine unit 5 MW										X		X			X				
Steam turbine unit 20 MW												X						X	

In a next phase also other biomass resources and technologies, e.g. other second generation biomass resources, will be considered and evaluated likewise.
The process chains are substructured using a modular scheme, grouping modules according to their position within the process chain. An example of this structure is given in figure 1 for biogas production from maize.

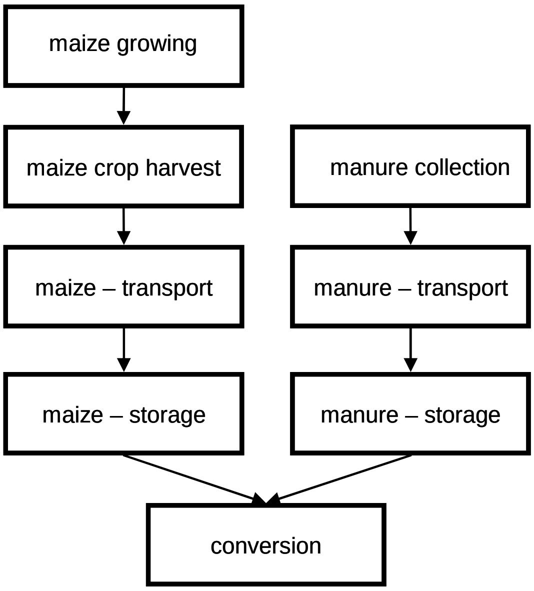

Figure 1: Set-up and modular structure of process chains in groups of modules for biogas production from mixed substrate of maize and manure

For each process chain a number of auxiliary and by-product flows are determined. Table 2 shows an exemplary list of these auxiliary flows also for biogas from maize silage.

Tab.2: Auxiliary and by-product flows for the process chain on biogas production from mixed substrate of maize and manure

Electricity mix Germany	Heating mix Germany	
Fertilizer K2O	Fertilizer P2O5	Fertilizer Calcium Ammonium Nitrate
Fertilizer Triazin	Lime, calcium carbonate	Concrete
Polyethylen	Cast iron	Reinforcing steel
Steel chrome	Foam glass	Steel
Traction engine	Diesel production	Agricultural engine
Trailer	Automized harvester	Maize seeding material

3 Methodological issues

BioEnergieDat aims to create and provide data sets of high quality for bioenergy supply chains. For this, development of an adequate methodology for ensuring and evaluating quality of datasets is indispensible part of the project.

Data quality in the project is understood following the definition from ISO 14040 as 'characteristics of data that relate to their ability to satisfy stated requirements'. It is, therefore, only relevant in the context of a specification of requirements [3, 7, 18]. Consequently, the project analyzes and compiles existing user needs in the context of bioenergy, analyzing German government sources, requirements of existing data quality networks such as ICLD and ecoinvent, and other sources.

In a second step, existing solutions for methodological issues for diverse user needs are collected and put in relation to the specifications. One example for such a relation is the need to apply a specific energy based allocation formula based on [17] if data sets are used in the context of the national German renewable energy statistics [18].

As a result, a common basis of shared specifications for many different applications in the context of life cycle assessment and bioenergy is developed, but also, specific requirements for specific applications are obtained.

For each data set, aim is to satisfy the common basis of shared specifications, and to maximize the number of specific applications. A user within a specific application context will then be able to use the datasets in a way that fits exactly to these requirements, and to, therefore, benefit from data sets of high quality.

Prerequisites for a successful application of this concept are the following:

- modular, unit process data sets that can be adapted to specific requirements, e.g. by applying a different allocation procedure as needed, or a different format and nomenclature as needed;
- information on the data set level about the kind of applications where the data set is appropriate for;
- a modeling software that allows users to select or specify the application context, and that then adapts the data sets and the calculations appropriately.

It will be rarely needed to invent new methodologies in the course of the project; rather, the connection between intended application and the data sets and life cycle models will be made operational by a smart data base and modeling software. Both are therefore closely linked to the methodological aspects in the project.

An aspect where new methodological developments in the project take place is the question of learning rates. Data sets for future periods (2020 and 2030) will be provided by the project as well. To this end, efficiency and learning materials reference curves for selected technologies are developed.

The conventional method of learning curves is based on the empirically observed relationship between cumulative production volume and a decreasing trend in costs. This ratio is presented by the learning factor f, indicating by what percentage the cost of a technology is reduced if doubling the cumulative production. The more mature a technology is, the smaller is f (so, for example, steam turbines have a learning rate of about 5 percent). The cost reduction described here includes three aspects: the technological learning (implementation of innovations), the economies of scale (upscaling from small to large plants) and the volume effect (mass production).

By transferring the learning rates to future periods, statements can be made on the development costs of technologies. Within BioEnergieDat this approach is further developed in order to update the material and energy needs from biomass plants based on existing costs and learning curves. For this purpose, a screening of existing data of learning rates was affected for the technologies within BioEnergieDat. The screening showed that there are very different conditions: For example, the existing learning rates refer to different components (the plant itself, the operation, the feedstock or two or three components) and different geographical areas. The reference value (the doubling steps) also varies between installed capacities, energy produced, mass of feedstock, etc. so that this approach might potentially not be applied to all considered technologies.

In a next step, it will be analyzed which absolute cost reduction might be expected by the year 2020/2030. This depends on how many doubling steps of the benchmark (power or energy supply) are possible until 2020/2030. These are calculated along energy scenarios in which the installed capacity and generated energy for biomass is updated for future periods. In this context, the results of a meta-analysis of existing energy scenarios in Germany and Europe will be used.

Moreover, it is necessary to analyze where in the considered technologies the cost reduction potential lies in detail and what share they make up of the learning effects. Thus, the mass production does only slightly or not at all affect the use of materials. On the other side, economies of scale effect, for example, a higher efficiency of a system that affects in a reduction of material inputs and emissions per unit of final product. In the context of fully developed facilities such as a cogeneration plant, the cost reduction will, however, be noticeable more on the feedstock.

Based on a combination of the two analytical steps, finally, the quantity structure of the current technologies will be updated to 2020 and 2030.

4 IT-Concept

For storage, management and generation of the LCI datasets, an Open Source IT-infrastructure is established, consisting of a web portal, a service oriented Internet accessible database for LCA data sets and an LCI dataset editor and modeling tool. This infrastructure allows storing and accessing needed data sets via the Internet directly via the LCA editor and modeling tool, and also by using a web based interface (data access area) to the data sets via the BioEnergieDat web site. The data access area is implemented through portlets: small web applications which can be integrated into web pages in case the website is built on top of a Java based portal server.

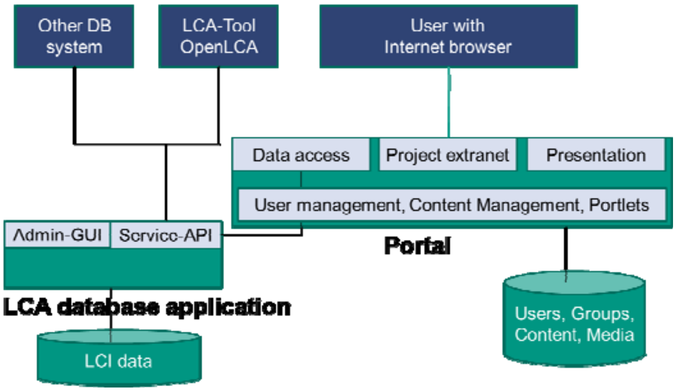

Figure 2: IT-infrastructure of the BioEnergieDat project

The modeling tool is developed based on the Open Source LCA software OpenLCA [19]. OpenLCA is translated to German language, and extended by an interface to directly interact with the BioEnergieDat database. This is more in detail described in a separate chapter [20]. Harmonized lists of elementary and product flow notions, accompanying physical flow properties and associated unit descriptions as well as basic background process data sets are provided early in the project via the central database application in software readable format. These can be directly used and accessed by data set authors from within the editor and modeling tool. Thus, common errors like wrong spelling and referencing of flow elements can be eliminated, using different units for the same flows within different process data sets or the creation of duplicate process and product flow data sets. Furthermore, the tedious work to find needed basic data sets by opening a web browser, searching and browsing web sites and downloading data sets manually has been eliminated.

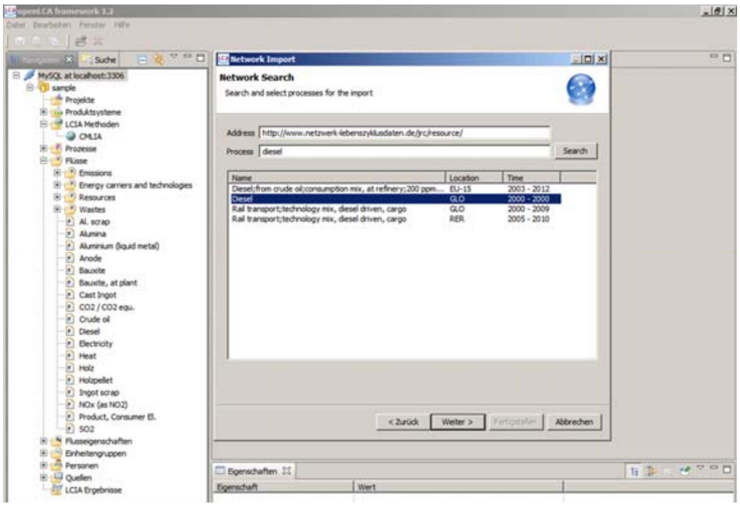

Figure 2: Searching and importing data sets from the database directly from within the modeling tool

The service interface between the database system and the modeling tool is built using the principles of RESTful web services, a technology to specify and implement Internet based service interfaces between distributed application parts which follows the principles of the web and is used commonly by most of the so called Web 2.0 applications. The RESTful service API of the database application allows it that arbitrary software applications written in different programming languages can easily create their own internal software interfaces for accessing and using the service provided retrieval and management functionality of the database system. The primary transfer of data sets between the database and tools is based on a variation of the ILCD (International Life Cycle Interchange Format) but the modeling tool and database application also allows the import and export of data sets in EcoSpold format. Thus, using the tool, data sets in both formats can be imported into the BioEnergieDat IT-infrastructure, stored in the database and then be provided to other project partners and third parties in both formats.

Because the data sets within the database system and the editor and modeling tool will be freely available after the project, third parties will have seamless and cost-free access to the data sets created within the BioEnergieDat project: either by downloading the data sets from the web site data access area in ILCD or EcoSpold format and importing them manually into their favorite LCA tool or by using the OpenLCA tool that is provided by the project, for their own modeling, which will give them direct access to the data sets from within the tool.

5 Conclusions

As main deliverable of the project BioEnergieDat, a data base of harmonized and consistent data sets on the most relevant bioenergy process chains will be made available. Data sets can be used in and adapted to a variety of different life cycle applications. On the basis of data sets, LCA studies as well as a robust evaluation of bioenergy process chains is possible in order to supply decision makers and bioenergy stakeholders with a reliable basis for further support and development with a focus on Germany. Above that, methodological developments, evaluation procedures and the Open Source IT may be used independently from project and data based and will provide more efficient tools and instruments for use in LCA and similar approaches.

6 References

[1] Sachverständigenrat für Umweltfragen, Sondergutachten Klimaschutz durch Biomasse, Erich Schmicht Verlag Berlin, 2007

[2] Zah, R., Böni, H., Gauch, M., Roland Hischier, R., Lehmann, M., Wäger, P., Ökobilanz von Energieprodukten: Ökologische Bewertung von Biotreibstoffen. Abteilung Technologie und Gesellschaft Lerchenfeldstrasse 5. CH-9014 Gallen St. Empa, 2007

[3] Cherubini, F., Bird, N. D., Cowie, A., Jungmeier, G., Schlamadinger, B., Woess-Gallasch, S., Energy- and greenhouse gas-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations. Resources, Conservation and Recycling, Jg. 53, H. 8, 2009/6, pp. 434–447.

[4] Cherubini, F.; Strømman, A. H., Life Cycle Assessment of bioenergy systems: State of the art and future challenges. Bioresource Technology, Jg. In Press, Accepted Manuscript

[5] Ciroth, A., Mathematical analysis of the ecoinvent LCI database with the purpose of developing new validation tools for the database, LCA IX, Boston, 2009, presentation

[6] Guinée, J., Heijungs, R., van der Voet, E., A greenhouse gas indicator for bioenergy: some theoretical issues with practical implications. The International Journal of Life Cycle Assessment, Jg. 14, H. 4, 2009, pp. 328–339.

[7] DIN EN ISO 14040 (2006). Umweltmanagement – Ökobilanz-Grundsätze und Rahmenbedingungen, Deutsches Institut für Normung DIN, Berlin

[8] DIN EN ISO 14044 (2006). Umweltmanagement – Ökobilanz-Anforderungen und Anleitung, Deutsches Institut für Normung DIN, Berlin

[9] European Commission Joint Research Center, ELCD core database version II, http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm. Zuletzt besucht am 03.03.2010

[10] ecoinvent Swiss Centre for Life Cycle Inventories – EcoSpold02 Release Beta 5, Februar 2010.

[11] Ciroth, A., Lundie, S., Huppes, G.: UNEP/SETAC Life Cycle Initiative, Life Cycle Inventory (LCI), Task Force 3, Methodological Consistency: Inventory methods in LCA: towards consistency and improvement. VDM-Verlag, 2008.

[12] Biomasse-Projekt Öko-Institut et al.: Projektberichte und Materialien, 2004, http://www.oeko.de/service/bio/de/index.htm

[13] Renewbility - Stoffstromanalyse nachhaltige Mobilität im Kontext erneuerbarer Energien bis 2030, Projekt Öko-Institut et al., http://www.renewbility.de/

[14] BMU-Biohandel EU 2005, http://www.ie-leipzig.de/Biomassenutzung/Biomasse.htm

[15] Final outcomes of EU-NEEDS project (New Energy Externalities Developments for Sustainability). http://www.needs-project.org/

[16] Vogt R.; Gärtner S.; Münch J.; Reinhardt G.; Köppen S.; Daniel J.; Postel J.; Scholwin F.; Klinski S.; Brohmann B.; Fritsche U.; Hennenberg K.; Hünecke K.; Rausch L.; Köppeö J.; Peters W.; Pusch E.; Schultze C. (2008). Optimierungen für einen nachhaltigen Ausbau der Biogaserzeugung und -nutzung in Deutschland. Bundesministerium für Umwelt, Verbundprojekt gefördert vom Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Projektträger: Forschungszentrum Jülich, F&E-Vorhaben, FKZ: 0327544, ifeu und Partner, Heidelberg, Leipzig, Berlin, Darmstadt, Mai 2008

[17] RICHTLINIE 2004/8/EG DES EUROPÄISCHEN PARLAMENTS UND DES RATES vom 11. Februar 2004 über die Förderung einer am Nutzwärmebedarf orientierten Kraft-Wärme-Kopplung im Energiebinnenmarkt und zur Änderung der Richtlinie 92/42/EWG, Amtsblatt der Europäischen Union, 21.2. 2004, deutsche Fassung

[18] Memmler, M.; Mohrbach, E; Schneider, S.; Dreher, M.; Herbener, R.: Emissionsbilanz erneuerbarer Energieträger - Durch Einsatz erneuerbarer Energien vermiedene Emissionen im Jahr 2007, Emissionsbilanz erneuerbarer Energieträger, Umweltbundesamt Berlin, 2009

[19] OpenLCA website, www.openlca.org

[20] Ciroth, A., Srocka, M., Düpmeier, Cl., Kusche, O., Schebek, L.: Interacting with the ILCD data network from an LCA software - the example of OpenLCA