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VALORGAS

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D6.1: Data on the operations involved in food waste management for energy recovery in standardised format for use in life cycle analysis

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Veolia Environmental Services (UK) Ltd (Veolia)

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Revisions

Changes since the original version [0] consist of removal of two broken links in references on first page and a correction to list of authors.

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Glossary of terms

CML2001: A well known LCIA (life cycle impact assessment method) developed by Leiden University in the 1990s

DTD: Document Type Definition; used in the Swedish Chalmers ISO/TS 14048 format for LCA datasets

ELCD: European Reference Life Cycle Data system

EU JRC-IES: European Union Joint Research Centre, Institute for Environment and Sustainability

GWP: Global Warming Potential; measured in kg of CO2eq

GWP100a: Global Warming Potential over a 100 year time frame; measured in kg of CO2eq;

HDPE: High density polyethylene; plastic used to manufacture wheeled plastic bins

ILCD: International Reference Life Cycle Data System; evolved from the ELCD data format around 2009

ISO: International Standardisation Organisation;

ISO/TS: ISO Technical Specification

ISO/TS14048: a standard entitled 'Environmental management-Life cycle assessment-Data documentation format';

JNLP: Java Network Launching Protocol; executable (Oracle/Sun Java) files are text files with a *.jnlp extension

LCA: Life Cycle Analysis

LCI: Life Cycle Inventory; contains all emissions and raw materials from the manufacture of the product

LCIA: Life Cycle Impact Assessment

mySQL: An open source database (software) used in openLCA (http://dev.mysql.com);

openLCA: LCA software from http://www.openlca.org

soda4LCA: short for service oriented database application 4 LCA; server side software from KIT (Karlsruhe Institute of Technology) at http://www.iai.fzk.de/www-extern/index.php?id=2219&L=1; ILCD Network nodes make their datasets available via soda4LCA

SPINE: Sustainable Product Information Network for the Environment; a Swedish LCA data format developed by the national competence centre CPM at Chalmers University of Technology; this data format is also known as SPINE@ CPM

SPOLD: Society for Promotion of Life-cycle Assessment Development;

STP: Standard Temperature and Pressure; 0_C and 101325 Pa

URL: Uniform Resource Locator; the URL is a locator for a resource; the URL provides a method of finding a resource on the internet

UUID: Universally Unique IDentifier; modern LCA formats such as the ILCD employ a 128-bit hex number that uniquely identifies the LCA dataset; "since UUIDs are unique and persistent, they make excellent Uniform Resource Names" (http://www.ietf.org/rfc/rfc4122.txt); the advantage to UUIDs is that, unlike URLs, they do not need a central registration and administration; the user generates her/his own UUID locally for the new LCA dataset

XSD: XML Schema Definition; defines the fields in *.xml _les; for example http://www.w3.org/2005/08/xml.xsd contains a Schema

XML: eXtensible Markup Language; a so-called meta (programming) language; based on text files; XML is easily extended; in contrast, HTML is not extendable and has a static, fixed format that limits its' use;

WRATE: Waste and Resources Assessment Tool for the Environment; standard software for LCA of waste processes in the UK - http://www.environment-agency.gov.uk/research/commercial/102922.aspx.

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1 Introduction

Life cycle analysis (LCA) is a comparatively new environmental discipline that is under continuous development, and can be regarded as a computationally intensive method. LCA was developed for consumer products in the 1990s but can equally well be used for the assessment of a variety of renewable bioenergy and biofuels (e.g. Delucchi, 2006; Zah et al., 2007; Curran, 2013). Research in LCA and waste management is ongoing, but the vast majority of studies do not provide access to the underlying data. This work brings waste data gathered within the VALORGAS project into one of the two most prominent LCA data formats available today:

1. The ILCD format (e.g. Stenull, 2010)
2. The ecoInvent®; format (http://www.ecoinvent.ch). [1]

A third, but now arguably abandoned format is the Swedish SPINE format based on DTD technology (Koskela and Hiltunen, 2004; Hischier and Kumlin, 2003, 2004). In the UK, WRATE appears to have adopted this ISO/TS14048 compliant data format developed at Chalmers University in Sweden.[2]

Benefits of bringing data into a standardised format are huge. LCA datasets can be made available digitally by practitioners on a global scale on distributed websites. They can be peer reviewed and improved by co-researchers. They can be developed further without the need to replicate the labour involved in the generation of datasets. In short, publishing not only studies, but also the underlying data in a standardised format is highly useful. As a comparatively young method in environmental sciences, LCA can be employed for waste-to-energy pathways and anaerobic digestion (e.g. Raysoni, 2002; Hartmann, 2006; Chaya and Gheewala, 2007; Yamyim et al., 2008; Pöschl et al., 2010; Jury et al., 2010; Rehl and Müller, 2011; Patterson et al., 2011; Poeschl et al., 2012a, 2012b; Rehl et al., 2012); Grosso et al., 2012; Bühle et al., 2012; De Meester et al., 2012; Mezzullo et al., 2013; Manfredi and Pant, 2013). None of these studies provide access to LCA datasets in their research.

A number of recent research projects have acknowledged that datasets need to be made public:

- http://www.ecotechsudoe.eu: EU funded Ecotech Sudoe LCA database, run by Martinez Carles and Xavier Gabarrell Durany. No data available yet at the time of writing.
- http://www.prosuite.org (PROspective SUstaInability Assessment of TEchnologies): An EU FP7 research project taking on LCA to assess sustainability of new materials and technologies. GreenDelta developed a prosuite plugin for their openLCA software.
- http://www.bioenergiedat.de: A German funded research consortium led by Prof. Liselotte Schebek in Darmstadt to harmonise bioenergy assessment at the Karlsruhe

[1] A statement from Bo Weidema at ecoinvent®; on the ELCD/ILCD format is at http://www.ecoinvent.org/news-events/news/newsdetails/view/ecoinvent-position-towards-the-ilcd-initiative-of-the-european-commission/.

[2] WRATE: http://www.environment-agency.gov.uk/research/commercial/102922.aspx.

Institute of Technology KIT. This is a fully functional ILCD dataset repository and can be considered as one of the first so-called ILCD Network nodes. A large number of datasets have been generated and are already available including biogas technology from energy crops at http://iai-uiserv1.iai.fzk.de/bioenergiedat/. The latter website runs the soda4LCA dataset server.

- http://www.ilcd-network.org: The upcoming European hub for distributed organisation of LCA datasets in ILCD format. The domain name has been registered by Marc-Andree Wolf, but is not yet active at the time of writing.
- http://www.VALORGAS.soton.ac.uk: This project, coordinated by the University of Southampton.

Biofuel process chains can be complex and research results in traditional refereed paper form ought to be supplemented with associated life cycle assessment datasets in digital format - a matter that is inhibited by paper-based thinking (e.g. Sefton, 2009) among researchers:

> "Conventional peer-reviewed publications generally provide summaries of the available data, but not effective access to data in a useable format". (Boulton et al., 2011, page 1634)

This ties in with the notion that public as well as scientific data bring more benefit to the community if they are made public (e.g. Murray-Rust, 2008; Murray-Rust, 2007; http://open-data.europa.eu, digital data curation http://www.dcc.ac.uk/resources/how-guides/cite-datasets, http://www.openaire.eu).

1.1 The ELCD/ILCD data format and the ELCD core database

The European ELCD database (**E**uropean reference **L**ife **C**ycle **D**atabase) was developed by the EU JRC-IES in Ispra, Italy (http://ies.jrc.ec.europa.eu/) and adopts the ILCD format. The ILCD format can be seen as the successor of the original European ELCD format version 1, first published in 2007, with the ILCD format 1.1 formally released in June 2009. The change from the term ELCD to ILCD was introduced through the increasing collaboration between LCA bodies in Brazil, China, Japan, Malaysia and Thailand (Kusche, 2009, page 232). The ILCD format follows ISO/TS14048 principles more strictly than existing formats.

The datasets generated in this deliverable are all based on the current ELCD version 3 core database, which serves as the background database. Various versions of the ELCD were released in chronological order as follows:

- **ELCD** core database **version 1**: Released in February 2007.
- **ELCD** core database **version 2**: Released in June 2009.
- **ELCD** core database **version 3**: Released 20 Feb 2013.

The term 'core' indicates that the database currently contains numerical datasets, but no LCIA methods yet. The latest ELCD database version 3 can be accessed and viewed in two ways:

1. **Offline:** Complete database as ELCD.zip file at http://lca.jrc.ec.europa.eu/lcainfohub/datasetDownload.vm.
2. **Online:** At http://elcd.jrc.ec.europa.eu/ELCD3/ via a web interface.

Typically, ELCD datasets for materials, energy carriers, transport, and waste management come from two sources:

- EU business and industry associations
- GaBi LCA datasets, purchased from PE International http://www.pe-international.com.

The ELCD database is under continuous development and the processes in the ELCD database are reviewed according to ISO 14040/14044 (http://www.iso.org/iso/catalogue_detail?csnumber=37456). The ELCD website provides stylesheets and XML schemas necessary to render native *.xml files in a standard web browser. The schema and stylesheets need to be copied next to the ilcd file containing the datasets for the html display to function. This ensures that all hyperlinks in the ILCD dataset are working. The rendering of xml to html is done on the fly on the web client (the remote user). A shortcoming of the ELCD database is that no uncertainty parameters are attached to the values, which makes Monte Carlo analysis impossible.

1.2 ILCD process datasets

The key information to model the waste-to-biogas chain will, in most cases, reside in process datasets. A total of seven possible types of LCA datasets are possible in the ILCD format as shown in Figure 1.

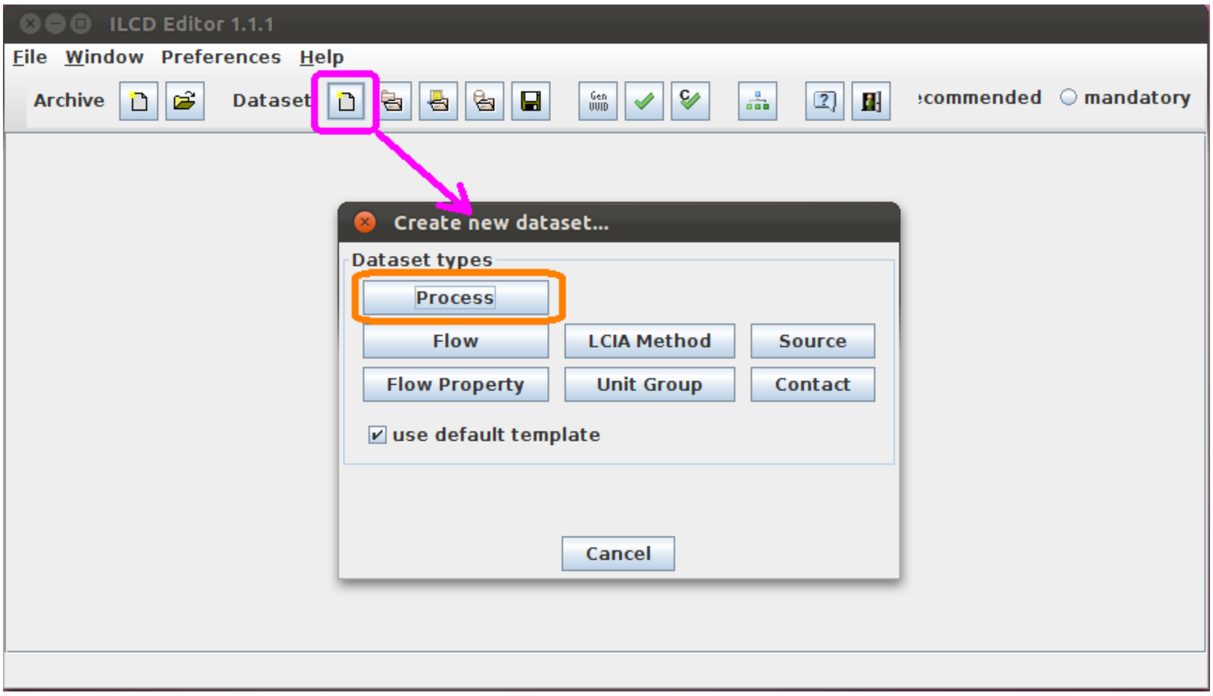

Figure 1. When a new dataset is created in the ILCD editor, the user has a choice of 7 types of ILCD datasets: (1) Contacts (2) Flows (3) Flow properties (4) Processes (5) Sources (6) Unitgroups (7) LCA methods.

For a new process dataset it is essential to find an appropriate and concise name for the process. With process datasets a total of 123 data fields can be populated and stored in the *.xml dataset file. Figure 2 breaks these 123 fields down into three types:

1. **Automatic fields:** Are filled in by the ILCD editor automatically.
2. **Mandatory manual fields:** Must be filled in by the user.
3. **Optional manual fields:** Can be filled in by the user.

Despite a total 123 fields, many of these only require a single word, or a single number, and the bulk of the work will go into describing the process and adding a drawing or an illustration to the process dataset. With process datasets the ILCD editor features five tabs:

1. Process information
2. Modelling and validation
3. Administrative information
4. Inputs and outputs (in form of flows per reference unit)
5. LCIA results

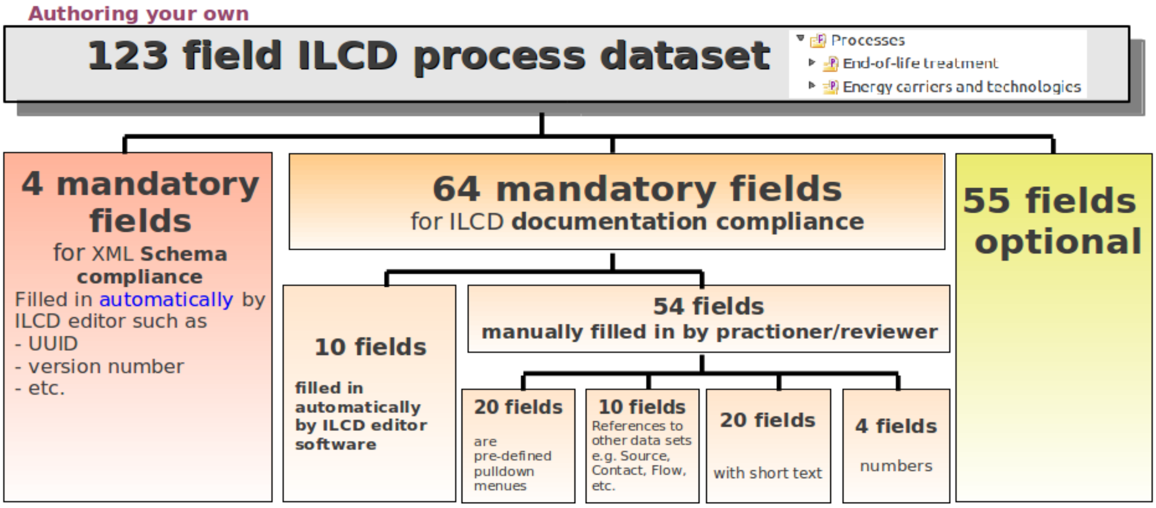

Figure 2. ILCD process datasets contain a total of 123 fields that can be populated with data or metadata. Generating ILCD dataset is accomplished with openLCA or the ILCD editor. The ILCD editor stores the data fields in a standardised *.xml file.

1.3 Principle of biogas upgrading with water scrubbing

Datasets described in this report employ a biogas upgrading technology known as water scrubbing. Carbon dioxide (CO_2) and hydrogen sulphide (H_2S) in biogas are undesirable and need to be removed. CO_2 is very soluble in water whereas CH_4 is not. The absorption of CO_2 into water is, however, limited at ambient atmospheric pressure. To reduce water consumption (or increase CO_2 absorption) water scrubbing is based on a counter-current principle:

1. **Absorption of** CO_2 **in column 1:** Water droplets are sprayed through biogas in the so-called absorption column at an elevated pressure, which accelerates CO_2 uptake.
2. **Desorption of CO_2 in column 2:** The absorbed CO_2 is released from the water in the so-called regeneration column at ambient pressure.

Hydrogen sulphide H_2S is a by-product of bacterial decomposition and is also absorbed by water. H_2S is very corrosive to metals and occurs in biogas in small quantities which partly depend on the type of feedstock. The absorption of both CO_2 and H_2S leads to increasingly acidic water with pH below 7. For the practitioner it is useful to understand factors that affect biogas upgrading with water scrubbing technology:

- **Biogas component gases:** Electricity use in upgrading depends on biogas quality i.e. the methane content. High methane content means lower electricity demand for upgrading.
- **Ambient temperature:** Uptake of CO_2 increases with decreasing water temperature (solubility of CO_2 in water increases). Solubility of CO_2 in water is much higher than that of CH_4.
- **Ambient pressure:** Increasing (partial) pressure of CO_2 increases the absorption of gases by water. Less solvent (water) and therefore less pumping is required to clean the biogas into pure methane.

Biogas upgrading requires pumps and compressors and it is important to minimise their use to reduce parasitic demand in the overall biogas process chain. Care has to be taken when the electricity consumption of the upgrading operation is reported - the options to report electricity parasitic use are

1. **Relative to upgraded gas:** Units are [kWh_{el} Nm^{-3}] i.e. electric energy consumed per normalised volume of upgraded biogas.
2. **Relative to raw gas:** Units are [kWh_{el} Nm^{-3}] i.e. electric energy consumed per normalised volume of raw (non-upgraded) biogas.

The former will be higher than the latter. For example, a biogas upgrading plant using water scrubbing could report parasitic electricity demand as 0.76 kWh Nm^{-3} of **upgraded gas**, or as 0.45 kWh Nm^{-3} **raw gas**.

2 Method

The aim is to demonstrate that high quality LCA datasets in a global format are relatively easy to generate and can be made available to the research community. Providing datasets makes it possible to start modelling the life cycle environmental impacts for biogas production from organic waste. All the generated datasets are based on the following:

- The latest ILCD format v1.1 was chosen for all datasets.
- The software packages 'openLCA' and 'ILCD editor' were used to generate selected datasets related to biogas from waste processes.
- The JRC's ELCD database version 3 served as the background database in openLCA v1.3[3].
- Apart from the ELCD no other commercial or non-commercial background database was employed. This makes the datasets transparent and available to the research community.

[3] At the time of writing (July 2013) the ELCD database at http://lca.jrc.ec.europa.eu/lcainfohub/datasetDownload.vm contained minor errors. The ELCD dataset 'highly radioactive waste', which is a product flow rather than a waste flow, is referencing 'UBP ecological scarcity' which in turn is referencing a unit group that does not exist. The missing unit group dataset has the UUID ea76b8b2-9712-4d51-96e8-8cc388273ae9.xml.

- Datasets were tested using the ecoInvent CML2001 method available from http://www.openlca.org/download_page in a single LCIA methods zip file (last accessed July 2013).

Process datasets contain primary data and the following three process datasets have been generated, as depicted by boxes with green borders in Figure 3:

1. 240-litre plastic bin used in organic waste collections.
2. Metener gas upgrading infrastructure.
3. Metener gas upgrading operation.

A number of smaller, administrative datasets referenced within the above process datasets were also generated. Datasets were documented as far as possible according to Wolf (2010).

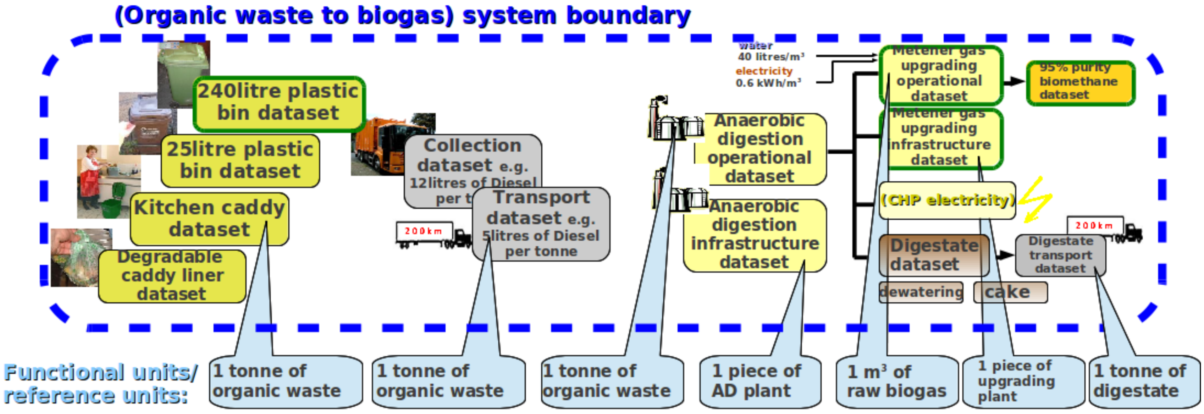

Figure 3. Proposed discretisation into datasets of a simple organic waste to biogas process chain. Events or process stages are depicted chronologically from left (collection) to right (digestate residue). Each box represents a potential LCA dataset. Flows in biogas upgrading are given per volume of **upgraded** biogas (not raw biogas).

A key activity in life cycle assessment is the development of a model and the allocation of activities to stand alone LCA datasets. Figure 3 is a proposed approach where each box represents an LCA dataset. There are numerous ways of organising the waste to energy process chain. Ideally, datasets should be modular, so that they can be used in other scenarios.

2.2 Modelling principles

Key concepts during the development of a process chain for LCA analysis are data (a) quality, (b) transparency, (c) careful selection of the functional unit FU and (d) careful selection of the lifetime/life span of the product (biogas plant infrastructure, 240-litre plastic bin). It is suggested that 1 tonne of food waste or organic waste serves as the functional unit for the biogas plant infrastructure. Medium scale biogas plants generate around 97 m^3 of biomethane from one tonne of food waste (Banks et al., 2011).

- **Complexity:** A biogas upgrading plant is a moderately complex system and modelling this process is probably less transparent than modelling a 240 litre plastic bin.

- **Background database:** The flow inputs in the process datasets in this report are all sourced from the ELCD version 3 database. openLCA provides its own set of reference flows, but these were not used to facilitate reading of the datasets in software other than openLCA.

If, for example, a biogas plant processes 5000 tonnes year^{-1} of food waste, and the life span of the biogas plant is 10 years, then the processing of 5000 tonnes of food waste would necessitate one tenth of the biogas plant infrastructure dataset. If the life span is assumed to be 20 years, then the processing of 5000 tonnes of food waste requires one twentieth of the biogas plant infrastructure dataset. Similarly, if the functional unit is one tonne of food waste, and the biogas plant life span is 10 years, this would require 1/50000 of the biogas plant infrastructure dataset. Similarly, life span needs to be preselected by the practitioner for the biogas upgrading unit, as this will determine the fraction of the upgrading infrastructure dataset that needs to be attached to the gas upgrading operational dataset.

The output flow for the process 'biogas upgrading' using water scrubbing is based on the lower calorific value of upgraded methane. In BS EN ISO 6976-1995 the lower heating value for methane = 50.043 MJ kg^{-1} and this can be converted to MJ m^{-3} as follows

$$50.043 \text{ MJ kg}^{-1} \times 0.7157474161 \text{ kg m}^{-3} = 35.82 \text{ MJ m}^{-3} \qquad (1)$$

Assuming a purity of 95 % for biomethane, the chosen lower calorific value for upgraded biogas is

$$0.95 \times 35.82 \text{ MJ m}^{-3} = 34.029 \text{ MJ m}^{-3} \qquad (2)$$

where volumes are given in normal m^3. For food waste to biogas conversion a substantial amount of energy consumption occurs in the organic waste collection stage. The ELCD database contains two datasets per lorry type, e.g. two datasets per 7.5 tonne lorry to allow for the two units [kg] and [tkm] (tonne km). Generated datasets were based on the product flow in [tkm].

2.3 Biogas upgrading with Metener technology

Metener (http://www.metener.fi) has developed its own water scrubbing upgrading technology; core data for the biogas upgrading system are listed in Table 1. It is important to note that this upgrading process excludes bottling of upgraded methane to high pressure. Bottling is not part of this dataset (Figure 4).

> "The upgraded product gas is H-level biomethane with energy content 36-50 MJ kg^{-1} and 30-40 MJ Nm^{-3}. The Wobbe index is 45.6-54.7 MJ Nm^{-3}. During normal operation, the upgrading unit produces a product gas with 92-99% CH_4 depending on the raw gas quality. Product gas contains 1-5% CO_2, < 2% inert gases and <1 ppmv H_2S. The upgraded product gas is dehumidified before entering the high pressure gas storage system (250-270 bar). Gas is dried using silica gel or alumina. The product gas after upgrading is completely odourless, and for safety it is odorised to allow leak detection." (Source: Kaparaju et al., 2012).

Electricity consumption for the upgrading operation is as follows:

"Average electricity consumption of the upgrading unit is approximately 0.5-0.6 kWh Nm^{-3} of raw biogas and 1.2-1.4 kWh kg^{-1} of upgraded and pressurised product gas at 250 bar including the electricity needs of the filling station. Electricity consumption for upgrading is mainly affected by the raw biogas quality. If the CH_4 content in the raw gas is high, the energy required for CO_2 scrubbing is less. In a cold climate, the electricity consumption is lower due to reduced cooling needs." (Source Kaparaju et al., 2012).

Here is primary information from the manufacturer on water consumption in the upgrading operation:

"a) From ... limited experience with ... low pressure test unit ... I could say around 20-50 liters per m^3 of upgraded gas. Only long term trials (months) in various conditions, loads and raw gas content could reveal true need for water changing. .... long term average with high pressure upgrader is 40 litres per m^3 of upgraded gas.
b) Water is recirculated as default in the production models. Without recirculation water consumption would be 200-300 liters per m^3 raw gas and 330-500 liters per m^3 upgraded gas." (Source: Personal email communication, Jussi Lantela, 11 April 2013)

Metener have pointed out that it may be possible to substantially reduce water consumption:

"...point out that energy figures with high pressure upgrading changed .... as mentioned in the D5.4 report. We installed more efficient water handling system so average consumption is now around 1 kWh/kg upgraded and pressurized and 0.45-0.48 kWh m^{-3} raw gas. ... most of the water is needed because we use it to cool the process. If we had a cooling refrigerator installed I suspect we don't need (to refill) water at all, except to compensate for some vaporization from the desorption unit and occasionally empty the system for a water filter change. A cooling unit will increase electricity need slightly by say 0.05 kWh kg^{-1} upgraded gas. I suspect this is the case in our commercial units as they will be fitted with refrigerating cooler units. Water intake can be minimized to 2-6 litres/kg upgraded gas. Water is not so cheap or abundant in places other than Finland and it may not be possible to consume it for cooling." (Source: Personal email communication, Jussi Lantela, 25 April 2013)

At a temperature of 273.15 K and a pressure of 101325 Pa one kg (normal standard conditions after BS EN ISO 133443-2005) of methane gas occupies 1.3971 m^3 (using the ideal gas law $pV = mRT$). A water consumption of say 4 litres kg^{-1} of upgraded gas corresponds to 2.86 litres m^{-3} of upgraded gas.

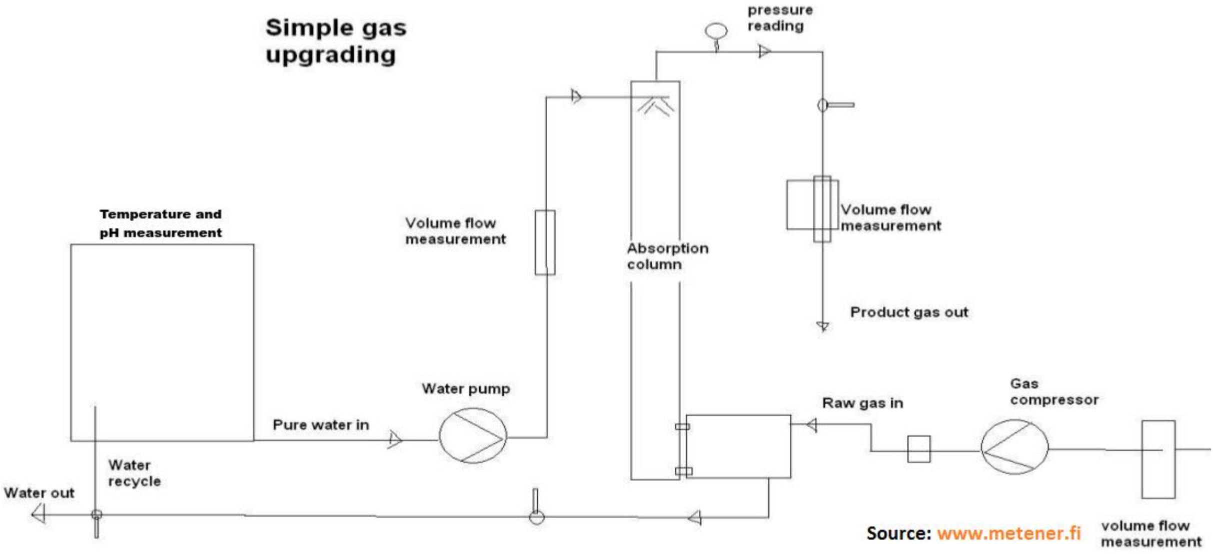

Figure 4. Flow diagram of Metener type water scrubbing rig in 2011 involving a water column. Source: http://www.metener.fi.

2.4 Infrastructure for Metener biogas upgrading

The dataset 'biogas upgrading plant infrastructure (water washing) www.metener.fi' was modelled according to a bill of materials supplied by Metener which were translated into the following inputs to the biogasupgrading infrastructure dataset using ELCD version 3 datasets (see Table 1 and Figure 5):

1. Rubber seals: For water and gas pipes a total 5 kg of 'acrylonitrile-butadiene-styrene granulate (ABS)'; amount listed in bill of materials supplied by Metener; the dataset may not be completely suitable and therefore represents an approximation.
2. Glass: 5 kg of 'Glass (formed and finished)'; amount listed in bill of materials supplied by Metener.
3. Building waste: 1000 kg of 'landfill of glass/inert waste'; authors' estimate.
4. Concrete for foundations: 4333 kg of 'portland cement (CEM I)'; Metener bill of materials stated 12000 kg of concrete; it is assumed one third of this is cement = 4333 kg.
5. Concrete for foundations: 1000 litres of 'process water'; authors' estimate.
6. Concrete for foundations: 8667 kg of 'sand 0/2'; Metener bill of materials stated 12000 kg of concrete; it is assumed two thirds of this is 12000 kg * 2/3 = 8667 kg of sand. Aggregate was not considered separately as this is likely to have the same impact as sand.
7. Steel for water tanks/pipes/reinforced concrete: 11000 kg of 'steel hot rolled coil'; info from bill of materials supplied by Metener;
8. Lorry transport: 20 tonnes over 100 km of 'transport in t*km' authors' estimate;

Table 1. Bill of materials serving as basis for inputs to the Metener gas upgrading infrastructure (embodied materials) dataset. Apart from rubber, all inputs are available in the ELCD version 3 database as flows. Rubber was replaced by a similar polymer.

	Quantity	Unit	ELCD v3 flow name
Construction material concrete 13000 kg assuming 1/3rd cement and 2/3rds sand:			
Portland cement (1/3rd)	4333	kg	Portland cement
sand (2/3rds)	8667	kg	sand
water	1000	kg	water
steel	11000	kg	steel hot rolled coil; steel sections
glass	5	kg	glass (formed and finished)
rubber	5	kg	seals and gaskets
polyethylene	25	kg	polyethylene low density foil
Goods transport/lorry travel			
Lorry 40 tonne	400	km	

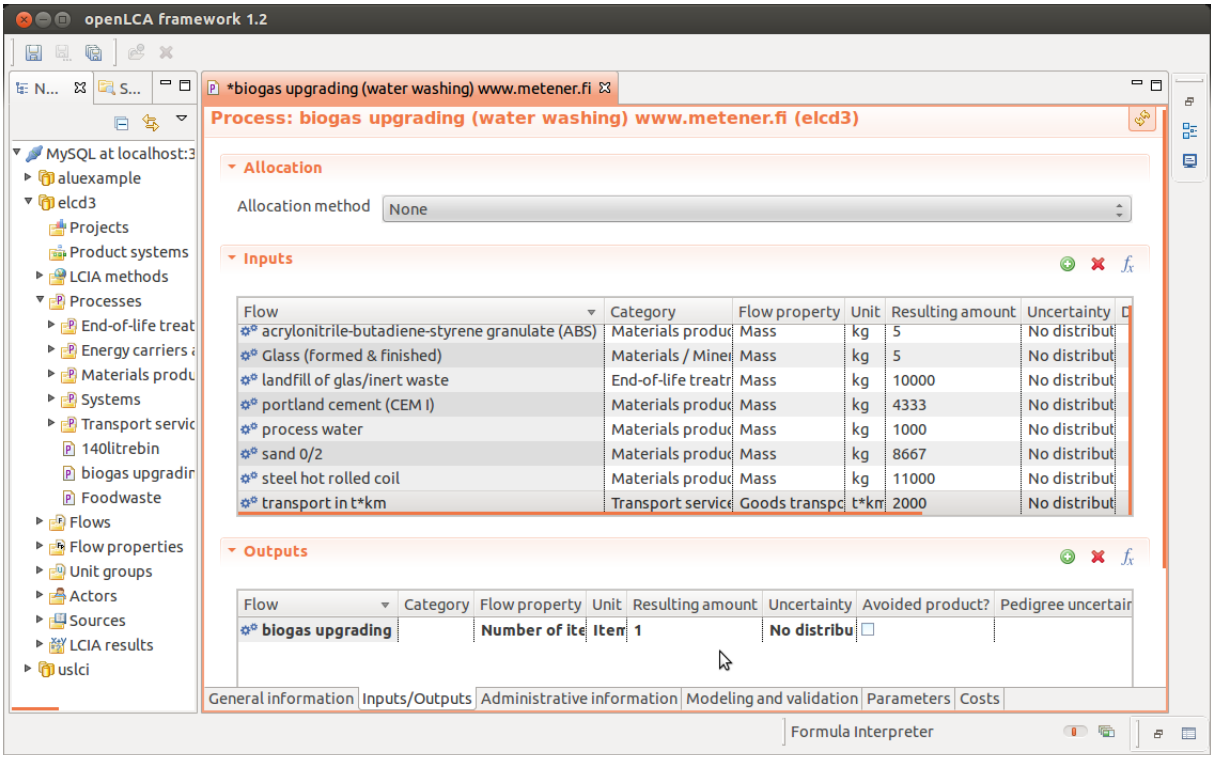

Figure 5. Input flows in the biogas upgrading infrastructure process generated in openLCA. There is a single output - one piece of upgrading plant.

2.5 Operational biogas upgrading - Metener

The biogas upgrading activity was implemented in a modular fashion. Operation and infrastructure were separated into two datasets. This has the following advantages:

- datasets are less heavily 'loaded', easier to comprehend, and more transparent.
- operational data changes do not mean replacing the upgrading infrastructure.

The two main input flows for the operational biogas upgrading dataset are water and electricity to drive the pumps and the only output is CO_2 and upgraded biogas:

1. **Water (input) for scrubbing:** 40 litres of water per m3 of raw input gas;
2. Electricity (input): Required to drive various pumps; 0.6 kWh of electricity is consumed per m^3 of raw input gas; this includes compression to 250 to 270 bar.
3. **Waste carbon dioxide (output) from upgrading:** It is assumed that 0.73 kg of CO_2 is removed per m^3 of raw input gas; this is classified as biogenic CO2.
4. **95 % upgraded biogas (output):** Upgraded biogas at a purity of 95 % is an output flow. It is possible to achieve higher purity at the expense of increased electricity and water consumption. This is a flow dataset rather than a process and is stored under Flows → Energy carriers and technologies → Renewable fuels.

The upgrading operation process dataset in openLCA is shown in Figure 6 and Table 2. In the majority of LCAs the operation is likely to cause considerably more environmental impact than the infrastructure, a phenomenon also known as the 'washing machine effect' (Cullen and Attwood, 2009).

Table 2. Biogas upgrading core data for biogas upgrading with water scrubbing based on http://www.metener.fi technology. All gas volumes are normalised volumes (N) at STP. Source: Correspondence with Metener 2012 and Kaparaju et al., 2012. All volumes indicate raw, unpurified gas. The electricity consumption includes upgrading and compression.

	Quantity	Unit	Description
Construction materials			
concrete	13000	kg	foundation
steel	11000	kg	pipes, tanks, valves, engines, pumps, reinforcing in concrete
glass	5	kg	meter screens, other displays
rubber	5	kg	insulation at connection between pipes
polyethylene	25	kg	pipes, connections
Maintenance materials			
water	20	$l\ m^{-3}$	water used for scrubbing raw gas; water is recirculated;
Energy input			
electricity	0.6	$kWh\ m^{-3}$	energy used for pumps etc. per m^3 raw gas
Energy output			
biomethane	22.7	$MJ\ m^{-3}$	energy yield in form of upgraded biogas per m^3 raw gas
biomethane purity	92 to 99	% CH_4	after upgrading; typical 92-95 % CH_4 content
Emissions			
water	40	$l\ m^{-3}$	water used for scrubbing (recirculated)
carbon dioxide	0.73	$kg\ m^{-3}$	removed from biogas per m^3 raw gas
hydrogen sulphide	3.4	$g\ m^{-3}$	removed from biogas per m^3 raw gas

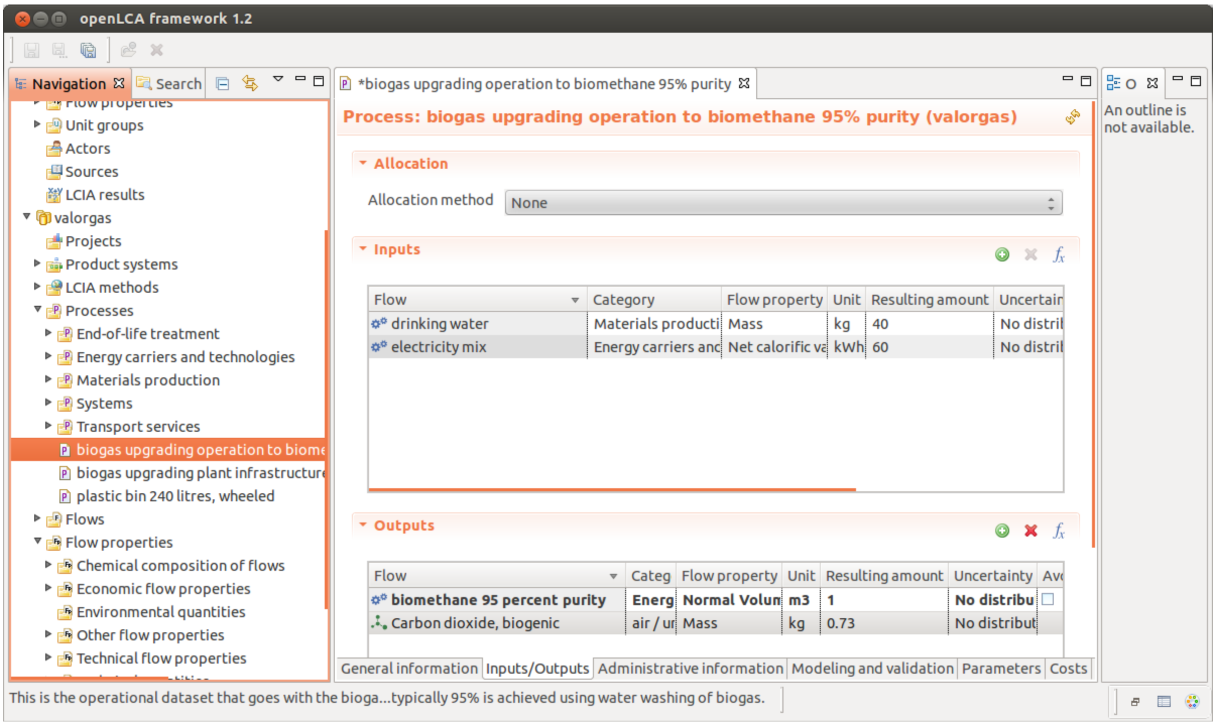

Figure 6. Metener gas upgrading operational process dataset in openLCA 1.2.9 using the ELCD version 3 database. Two inputs and two outputs are modelled

2.7 LCA dataset for 240-litre plastic bin

The ILCD dataset is based on primary measurements undertaken by the authors. A single 240-litre bin consists of 2 plastic wheels, a steel axle and the plastic body with lid. A standard 240-litre bin as shown in Figure 7 was dismantled and parts were weighed. Results are given in Table 3. The values were compared with the 240-litre bin dataset in WRATE, which gave higher weights. WRATE also took maintenance of the 240-litre bin into account in the form of 4 kg of water and 0.01 kg of detergent. Water consumption appears unrealistic over the life time of the bin, and this was increased to 40 litres as shown in Table 3.

Figure 7. Standard 240-litre plastic bin, manufactured by SULO, used to store food waste in an institutional organic waste scheme. The bin was taken apart and parts were weighed.

- **Wheel tyre material:** The nearest dataset for the outer tyre part of the two wheels in the ELCD version 3 database was 'polybutadiene granulate (PB)' as shown in Figure 8. For each wheel the dry weight of 605 g was taken as the amount of polybutadiene granulate (PB) used during manufacture of the tyre (excluding the rim). This is an approximation as the rim and the rubber tyre were not taken apart and weighed separately. After consultation with a tyre manufacturer it was confirmed that styrol butadien rubber (SBR) may be the raw material for the tyre, but since wheeled bins do not go fast and for long distances, and to keep the price low for this high-volume item, it is likely that recycled plastic material is added during manufacture (Source: Personal email communication with Hartmut Weinhold, Continental, Hannover, Germany, on 6 August 2013). The use of pure polybutadiene granulate from the ELCD database may thus slightly overestimate the resources used during manufacture.
- **Wheel rim:** A single wheel was assumed to contain 605 grams of HDPE granulate - half of the total mass of a wheel. Again, this is an approximation as the wheel was not taken apart and parts weighed separately.
- **Steel axle:** The plastic bin's axle weighed 600 g. The dataset used is 'steel hot rolled section, production mix, at plant, blast furnace and electric arc furnace route'. This can be compared with WRATE, which used an amount of 1510 g of steel for the bin axle.
- **HDPE for bin body and bin lid:** The bins body excluding axle and wheels but including the lid weighed 12.260 kg and this was taken as the amount of HPPE granulate used in the manufacture of the bin (Figure 8). The ELCD version 3 dataset is called 'polyethylene high density granulate (PE-HD), production mix, at plant'.
- **Water:** It is assumed that the 240-litre bin is cleaned with 40 litres of drinking water over its life time (and detergent/washing up liquid). The water flow dataset from the ELCD version 3 database is under Flows → Materials production → Water → drinking water, as shown in Figure 9. The ELCD version 3 dataset was called 'Drinking water, production mix, at plant, water purification treatment, from groundwater'.
- **Electricity consumption/electricity mix:** A UK manufacturer (http://www.straight.co.uk) quoted (private communication with Douglas Forrest, plant manager in Hull, UK, Straight plc, May 2013) that per bin 8 kWh of electricity are consumed for the bin body alone excluding the plastic lid. A total of 15 kWh of electricity has been adopted in the model to allow for the lid and overhead in the manufacturing plant. Note that in WRATE the 240 litre bin does not contain electricity consumed during manufacture. The chosen electricity mix in the ELCD version 3 database was 'Electricity Mix, consumption mix, at consumer, AC, 230-240V'.
- **Transport:** It is assumed that, per bin, a total of 20 kg of raw material such as plastic granulate, wheels and axle steel is transported over 100 km. Transport of 20 kg = 0.020 tonne over 100 km amounts to 2 tonne kilometres per manufactured 240 litre bin. The chosen mode of transport was 'Lorry transport, Euro 0, 1, 2, 3, 4 mix, 22 t total weight, 17,3t max payload'. Note the comma rather than the point - the dataset is sourced from the German GaBi database.
- **Detergent (not modelled):** It is assumed that 0.1 litres of detergent (washing up liquid) is used during the life time of the bin. However, there is no detergent available in the ELCD database and therefore this input was not modelled. openLCA offers a flow called 'Detergents, unspecified' in its default reference flows. Because this flow

is foreign to the ELCD and has no matching (ELCD) process dataset[4] catering for inputs from manufacture of detergent, this flow was not utilised.

- **Wastewater (not modelled):** If 40 litres of drinking water are used to clean the plastic bin over its lifetime, an equal amount of wastewater would be generated but this is not currently modelled. The ELCD does contain waste water flows. In theory this would present untreated wastewater that is either going into the sewer or into the environment.
- **Recycled HDPE granulate (not modelled):** Recycling of plastic would need to be implemented in the openLCA graph window and not in the dataset itself. Recycling has not been included.
- **Output water (not modelled):** Water used in the upgrading operation may require treatment after use. This has not been taken into account.

The complete model of the process dataset under openLCA v1.2.9 is illustrated in Table 3 and Figure 10.

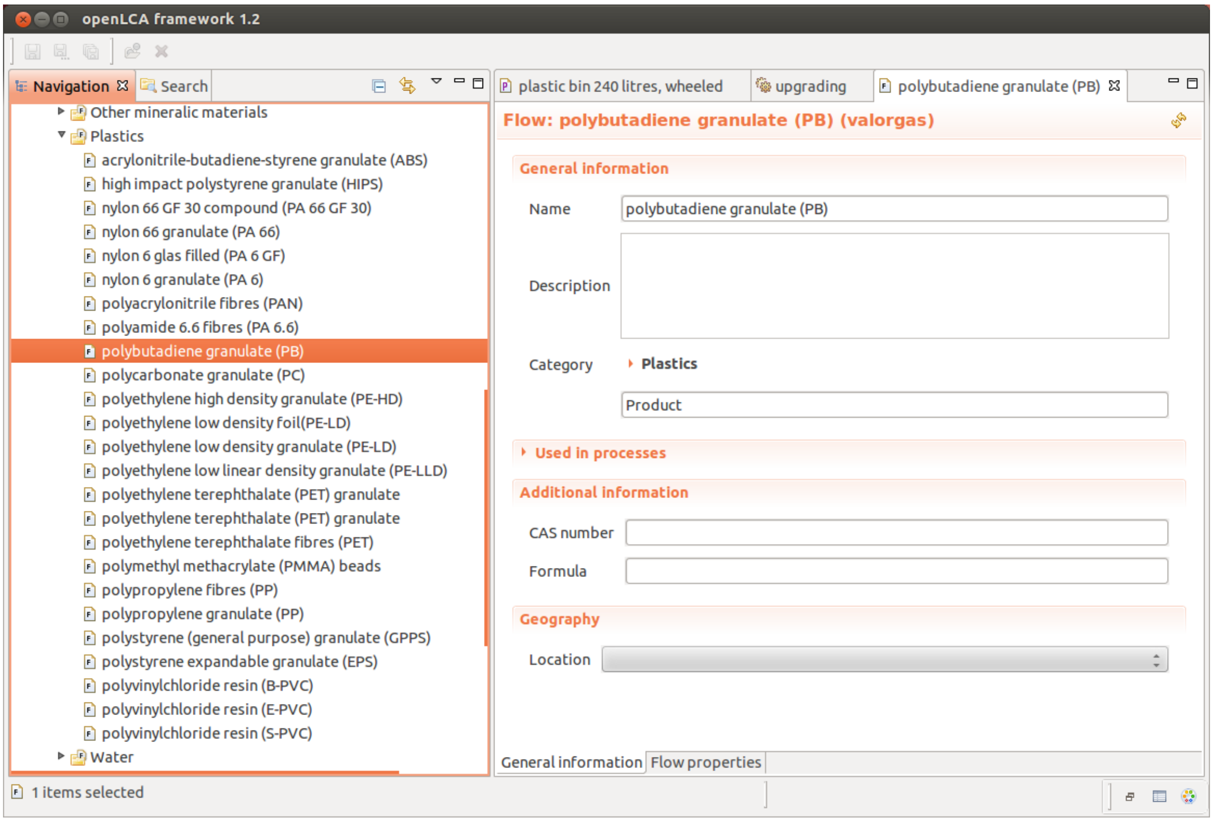

Figure 8. Choice of plastic flows in the ELCD version 3 database under openLCA v1.2.9. The outer thread of the plastic wheels on the bin have been represented by 605 g of polybutadiene granulate per wheel.

[4] No process datasets are provided in the default openLCA reference datasets. Entering a flow alone into the model would have no impact or effect whatsoever if the flow dataset cannot be linked with a matching process in the openLCA graph window.

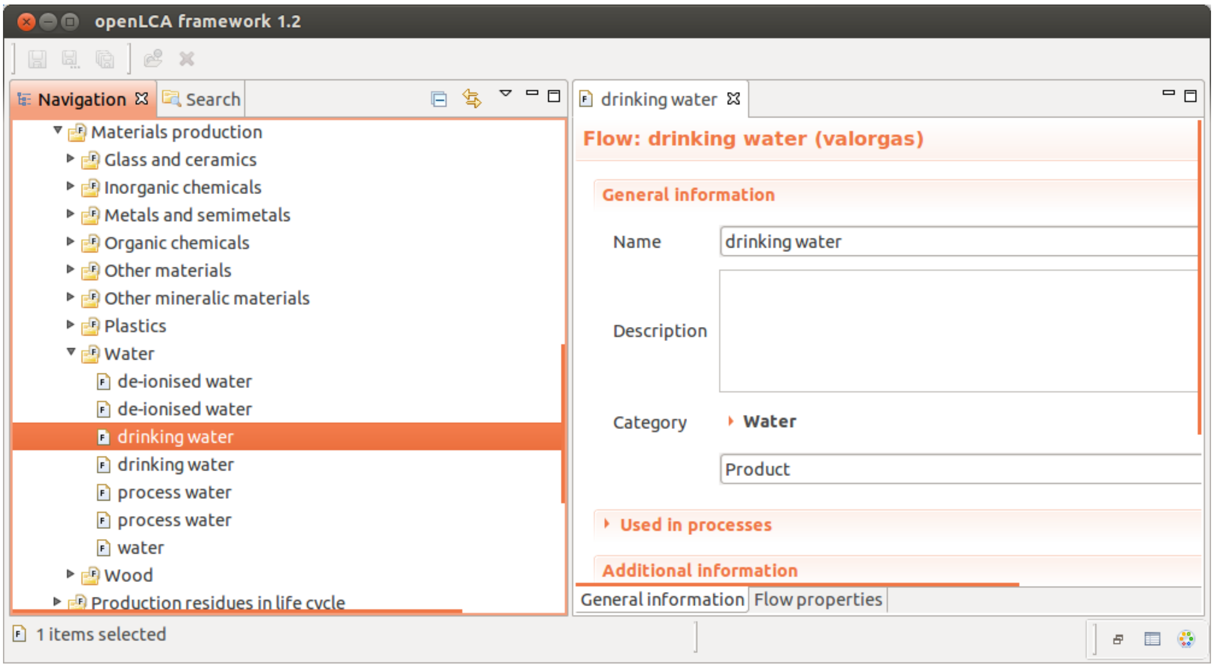

Figure 9. Choice of water ows in the ELCD version 3 database under openLCA v1.2.9. A total of 40 litres of drinking water is assumed to be used during the life time of the 240 litre plastic bin for cleansing.

Table 3. Collecting data for the 240-litre plastic bin dataset. A 240-litre plastic bin was taken apart and parts were weighed. Values are compared with data in WRATE's 240-litre bin.

Item	**This study**	**WRATE version 2012**	**units**
Construction materials			
bin body with lid (excl. wheels/axle):	11050	14500	g
Single wheel:	1210	1060	g
of which 50 % is HDPE:	605	-	g
and 50 % is rubber:	605	-	g
Steel axle:	600	1510	g
Complete bin including 2 wheels/axle:	14070	17070	g
Manufacturing			
Electricity consumption in manufacture:	50	0	kWh_{el}
Transport of plastic granules and steel: (i.e. transport of 20 kg over 100 km)	2	0	tkm
Maintenance during operational phase			
Water:	40	4	kg
Detergent:	0.1	0.01	kg

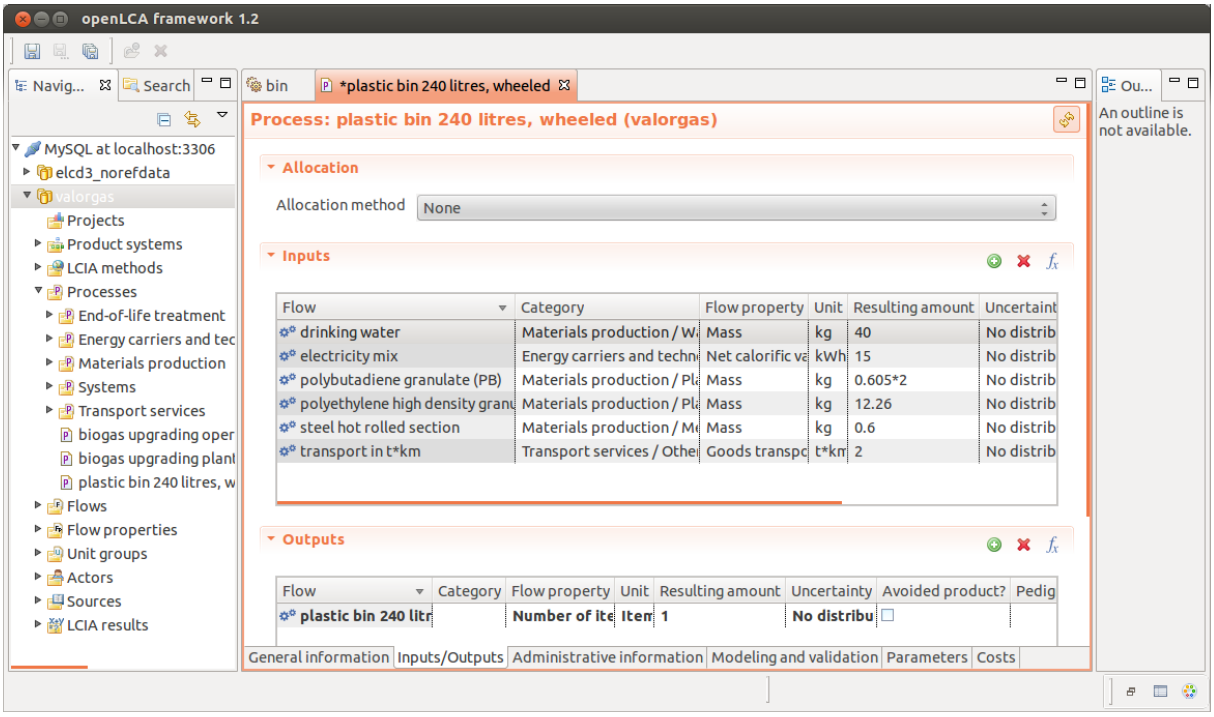

Figure 10. The new ILCD dataset 'plastic bin 240 litre, wheeled', generated in openLCA v.1.2.9 using the ELCD version 3 database. In total six flows serve as inputs for the model. The output is one 240 litre bin. Detergent for cleaning the bin during the life time was not modelled.

3 Results and discussion

A number of exemplary datasets were generated in ILCD format. All datasets are made available to the research community at http://www.VALORGAS.soton.ac.uk/lca/ILCD as shown in Figure 11.

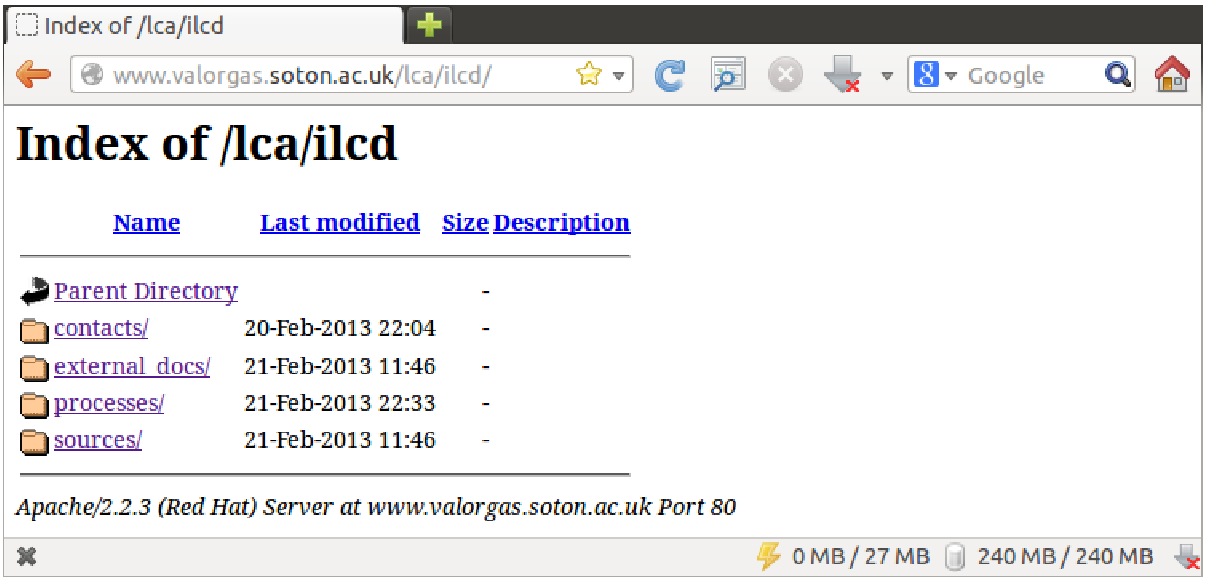

Figure 11. LCA datasets are available on http://www.VALORGAS.soton.ac.uk/lca/ILCD/. The two folders schemas and stylesheets in the parent directory contain the *.xml and *.xst files required to format the LCA datasets for display in a web browser.

3.1 Generated datasets

The new datasets are stored in an ILCD folder on the VALORGAS website for display purposes. The folder only contains the newly generated datasets and no datasets referenced in these files. This means the new datasets display correctly but the links in the new datasets do not as they point to files that are not present. Emphasis was given to data transparency and simplicity and the following datasets in ILCD version 1.1 format were generated:

1. **Contact dataset:** University of Southampton http://www.VALORGAS.soton.ac.uk/lca/ILCD/contacts/11962cce-2819-49f9-87fd-fa7f995a04d7.xml. Using the ILCD editor, the data set is ILCD data format compliant and passed the ICLD check successfully.
2. **Contact dataset:** Metener Oy at http://www.VALORGAS.soton.ac.uk/lca/ILCD/contacts/1348a8d1-b3b9-4099-9d2a-1616cc7492e3.xml. Using the ILCD editor, the data set is ILCD data format compliant and passed the ICLD check successfully.
3. **Resource dataset:** Water scrubbing flow diagram http://www.VALORGAS.soton.ac.uk/lca/ILCD/sources/2a06c2d8-fd74-4cf3-bc2c-4a26a4019be6.xml. Using the ILCD editor, the data set is ILCD data format compliant and passed the ICLD check successfully.
4. **Resource dataset:** Plastic bin 240 litres, wheeled, http://www.valorgas.soton.ac.uk/lca/ILCD/sources/bc34b8c3-5e50-488b-92b0-b4b46775bd31.xml. Using the ILCD editor, the data set is ILCD data format compliant and passed the ICLD check successfully.
5. **Process dataset:** Biogas upgrading infrastructure http://www.VALORGAS.soton.ac.uk/lca/ILCD/processes/6118cb8e-b058-4ef9-b857-a0b9ff22f2b2.xml. Using the ILCD editor, the data set is ILCD data format compliant but not ICLD handbook compliant.
6. **Process dataset:** Biogas upgrading operational dataset http://www.VALORGAS.soton.ac.uk/lca/ILCD/processes/b407e5d2-ecba-4aaf-a04a-7235400c35ec.xml with a water flow of 40 litres Nm^{-3} of upgraded biogas (biomethane) and an electricity consumption of 0.6 kWh Nm^{-3} of upgraded biogas (biomethane); reference flow is one Nm^3 of upgraded biogas. Using the ILCD editor, the data set is ILCD data format compliant but not ICLD handbook compliant.
7. **Process dataset:** 240-litre wheeled bin after EN 840 http://www.VALORGAS.soton.ac.uk/lca/ILCD/processes/e6875763-93bb-4d1a-ac45-35dd0fdc3774.xml. Using the ILCD editor, the data set is ILCD data format compliant but not ICLD handbook compliant.
8. **Flow dataset:** 240 litre wheeled bin after EN 840 http://www.valorgas.soton.ac.uk/lca/ILCD/flows/f7208eaf-04db-42f3-a070-8f9de97569cf.xml used as the product flow in the above 240 litre process dataset. Using the ILCD editor, the data set is ILCD data format compliant and ILCD handbook compliant.
9. **Flow dataset:** Biomethane 95 % purity from biogas upgrading operation http://www.valorgas.soton.ac.uk/lca/ILCD/flows/8fbeaf20-2106-4293-ba14-9a5f9f6c9de0.xml; one m3 normal volume with a lower calorific value of 34.029 MJ per m3. Using the ILCD editor, the data set is ILCD data format compliant and ILCD handbook compliant.

Ancillary datasets such as contacts, sources and flows were generated first.

3.2 Dataset quality and ILCD compliance using the ILCD editor

The aim was to make the new datasets ready for submission to the forthcoming ILCD Data Network and this requires high quality data. There are two levels of quality checks in the ILCD editor 1.1.1 which were both used for the new data sets:

1. **'Validata data set':** This ensures all mandatory xml fields have been filled in correctly.
2. **'ILCD Handbook compliance':** This check is slightly more demanding and tests against criteria laid out in the ILCD Handbooks such as Wolf et al. (2012).

With the simpler data sets such as contact data sets (Figures 12 and 13) it was straightforward to obtain both levels of quality assurance. With process data sets it was more difficult to achieve the stricter ILCD handbook compliance. It was helpful to start with a current ELCD process data set as a basis where compliance is guaranteed, and then gradually adapt it to the new data set to avoid dealing with numerous error messages at once if a completely new data set is used. It should be noted that the ILCD editor can only test for mechanical compliance but cannot test the contents of the various data fields including correct nomenclature. This would need to be carried out manually by a qualified data set reviewer.

Even though the underlying data in all three process data sets were thoroughly researched, they can probably be improved and were chosen to be only entry-level compliant. This entry level compliance is referenced in the process data set by pointing to d92a1a12-2545-49e2-a585-55c259997756.xml (Table 3 in Wolf et al., 2012).

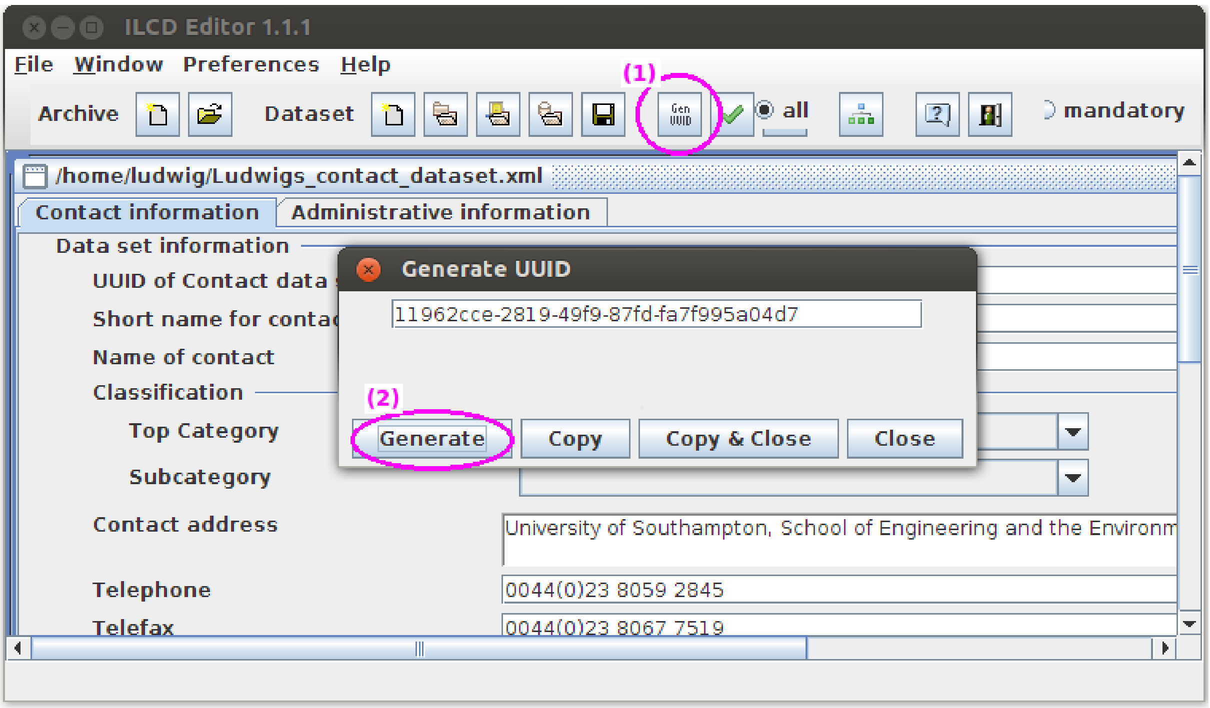

Figure 12. Generating the UUID string in the ILCD editor for the contact dataset 'University of Southampton'.

Contact data set: University of Southampton (en)	
Contact information	
Data set information	
Short name for contact	University of Southampton
Name of contact	Sonia Heaven, Keith Riley, Ludwig Gredmaier
Contact address	University of Southampton, School of Engineering and the Environment, Highfield, Southampton SO17 1BJ, UK
Telephone	0044(0)23 8059 2845
Telefax	0044(0)23 8067 7519
E-mail	s.heaven@soton.ac.uk; k9riley@aol.com; ludwig.gredmaier@web.de;
WWW-Address	http://www.valorgas.soton.ac.uk/LCA/ILCD
Contact description or comment	Datasets developed within the European Union 7th Framework programme FP7, grant number 241334, acronym "Valorgas", Valorisation of Food Waste to Biogas, running 1 March 2010 to 31 August 2013.
Administrative information	
Data entry by	
Time stamp (last saved)	2013-02-19 09:23:20.527 UTC
Data set format(s) (source data set)	ILCD format
Publication and ownership	
UUID of Contact data set	11962cce-2819-49f9-87fd-fa7f995a04d7
Data set version	01.00.000

Figure 12. Contact dataset for 'University of Southampton' as stored on http://www.valorgas.soton.ac.uk/lca/ILCD using the EU supplied stylesheets for display in a web browser. The contact dataset is the simplest among the seven LCA dataset categories.

3.3 Gas upgrading infrastructure Sankey diagram

A Sankey diagram of GWP arising from the infrastructure of a biogas upgrading unit is shown in Figure 14. The diagram was generated in openLCA and the thickness of the connections between boxes indicates the relative amount of CO_{2eq} emissions per activity or per building material. As expected, steel and cement contribute most to the CO_{2eq} emissions. Transport and other materials contribute comparatively little towards the overall CO_{2eq} emissions of the upgrading plant.

3.4 Complete *.olca database

In addition to the individual files in *.xml format, the complete ELCD version 3 database including all of the new datasets generated in this work are made available in a single openLCA database file at http://www.valorgas.soton.ac.uk/lca/valorgas.olca (12MB). The *.olca database was exported in openLCA version 1.2.9 (April 2013) into a single, compressed mySQL file.

- The *.olca database can be imported back into openLCA easily for viewing, running an assessment or to generate further datasets.
- Care needs to be taken about the LCIA methods in the *.olca database. These methods are taken from http://www.openlca.org/download_page (last accessed July 2013) and may be unsuitable for serious LCA for two reasons:
  - **Characterisation factors:** They contain only a subset of characterisation factors compared to the full ecoinvent method.
  - **Flow mismatch:** The LCIA methods are ecoinvent methods and thus are unlikely to link to all the output flows of the ILCD datasets used in this work.

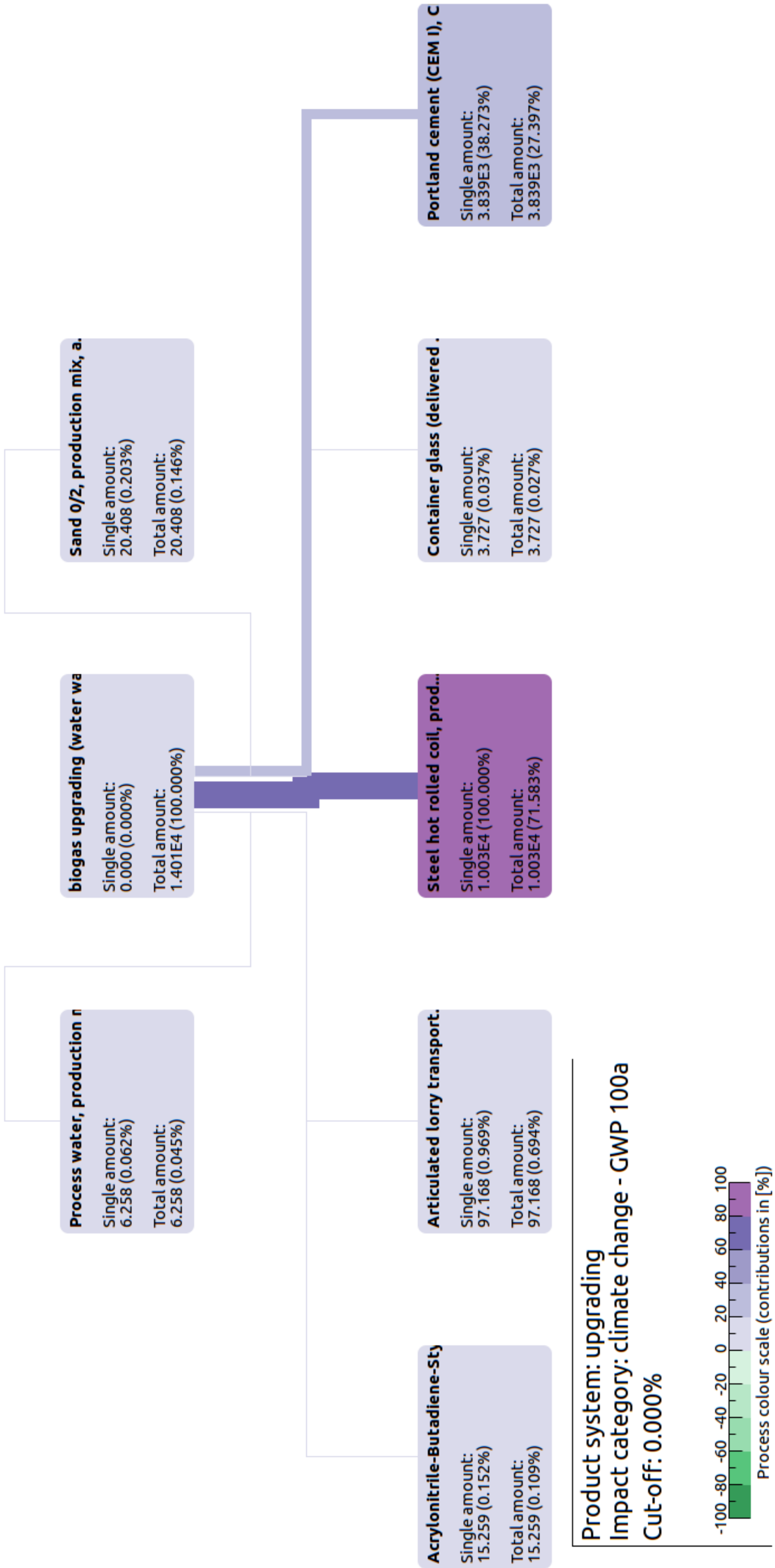

Figure 14. Sankey diagram of GWP100a for the Metener biogasupgrading **infrastructure** dataset. The thickness of the arrows indicates the individual contribution towards the total GWP of the gas upgrading infrastructure.

3.5 Pilot ILCD node at the University of Southampton

The forthcoming ILCD Data Network (Kusche et al., 2012) is designed as a distributed network of server nodes. These nodes are running the soda4LCA web application. Nodes would typically consist of a virtual machine with a tomcat servlet engine (running the application) and a mySQL database in the background to hold the datasets. The soda4LCA application was installed as a pilot service at the University of Southampton in Summer 2013 at http://life-cycle.data.soton.ac.uk. The datasets generated so far are made available using the soda4LCA ILCD node as shown in Figure 15. Anybody interested in making his/her LCA datasets available in ILCD format can upload LCA datasets for others to use. The service provides essentially two functionalities:

- Download of LCA datasets in ILCD format: Anybody looking for LCA datasets in ILCD format can access the server and search the node or the node network.
- Upload of LCA datasets in ILCD format: More importantly, practitioners and researchers are encouraged to upload high-quality LCA datasets in ILCD format onto the node. At the time of writing uploading is only possible within openLCA software.

The usefulness of the server increases as more researchers and practitioners upload datasets.

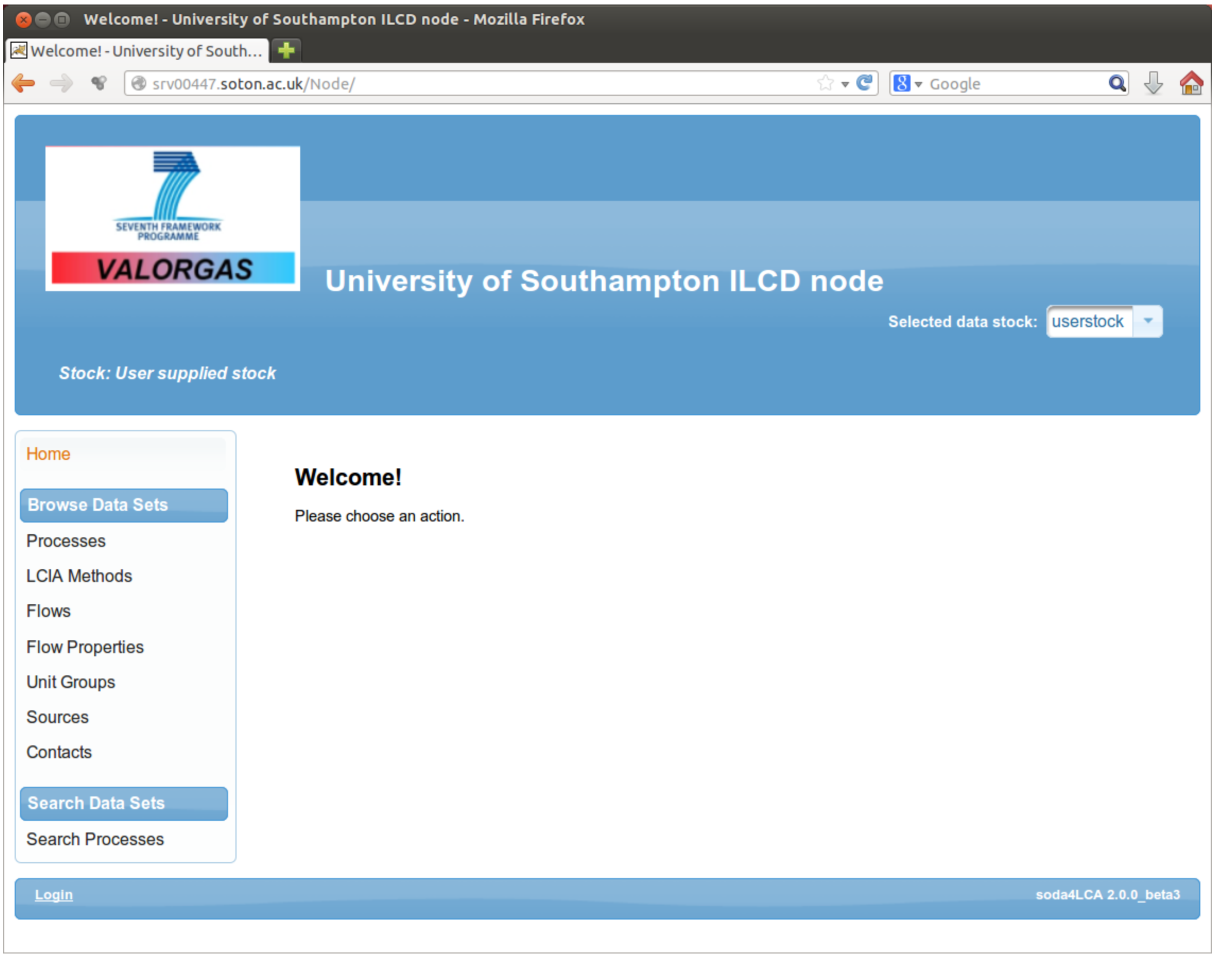

Figure 15. Web interface for the pilot ILCD node set up at the University of Southampton in summer 2013. Datasets are made available to the research community from this webserver running soda4LCA.

3.4 Limitations

The presented datasets have been developed using best available information but the following limitations need to be born in mind:

1. Currently no statistical distributions are attached to the process datasets. Should the datasets be used to model the complete organic waste to biogas process chain, statistical distributions would allow the establishment of confidence intervals for the chosen environmental impacts.
2. Input flows in all process datasets can be improved by re-sampling data from manfacturers. Gas upgrading kits are sold in low quantities and no two upgrading kits are identical. With Metener water scrubbing technology it is difficult to fix water consumption in the upgrading operation. Water consumption could be between no water at all (if a cooling refridgerator is installed and ambient temperatures are low) and 40 l m^{-3} of upgraded biogas. The practitioner needs to be wary of this uncertainty.
3. Life time/life span of the gas upgrading kit is hard to estimate.
4. In order to be able to create an anaerobic digestion plant LCA dataset, it is necessary to determine all input and output flows first. Data on emissions are scarce and a large number of assumptions will need to be made.
5. No ILCD LCIA methods were available at the time of writing. The ecoinvent CML method was used in this pilot study.
6. To some extent subjective decisions need to be taken when materials, maintenance and transport are chosen for a product, as in the case of the 240-litre bin in Table 3.
7. The assumption that the 240-litre bin is manufactured from 100 % virgin plastic granulate may not be realistic. For larger bins at least small amounts of recycled granulate are common.
8. An attempt was made to document all datasets according to Wolf (2010). Documentation may need to be improved.
9. Recycling of embodied building materials after the life span of the plant would need to be implemented. This would alleviate the environmental impact.
10. Data sets have not been peer reviewed.

Many more datasets are required to be able to model the life cycle impacts of the complete waste-to-biogas process chain.

4 Conclusions

Several datasets in standardised ILCD *.xml format were generated and made available to the community under http://www.valorgas.soton.ac.uk/lca/ILCD. The following conclusions can be drawn:

1. To the authors' knowledge no published LCA studies contain data in ILCD digital format.
2. This report documents experience gained during the preparation of new ILCD datasets in the field of biogas-from-waste. The process of generating datasets in openLCA/ILCD editor is straightforward.
3. The ILCD standard provides common ground for the assessment of biofuels. The ELCD database v3 currently contains a limited number of around 400 process datasets. To become a mainstream database it is vital that practitioners support and expand the

database by making available quality datasets in fields where the practitioner can provide expertise. This report documents datasets to assess renewable biogas from waste.

4. The schemas and stylesheets template files made available by the JRC make it straightforward to store and distribute proprietary LCA datasets on websites.
5. To become a fully functional LCA option, it is important to develop LCIA methods and make them available in the ELCD database.
6. Inputs, outputs and emissions in the complete organic waste to biogas process chain need to be established to allow assessment of this waste to energy technology using LCA. This report is a first step towards achieving this.
7. The ILCD data format provides an opportunity to harmonise data for research into renewable fuels with a European and global reach. Making LCA datasets available in digital format ought to be made compulsory for LCA studies.

In order to demonstrate the usefulness of the datasets for the assessment of biogas from organic waste technology, more datasets need to be generated for a model of the complete biogas production chain.

4.1 Future work

This report documents the establishment of datasets in ILCD format in a biogas from food waste context. A full model of the biogas from food waste chain is possible and promising but requires careful emissions modelling. A full model can shed light on the benefit of conversion technologies such as (a) biomethane to electricity or (b) biomethane to vehicle fuel. Identification of the energy conversion pathway that bears maximum environmental benefit is thus within reach.

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