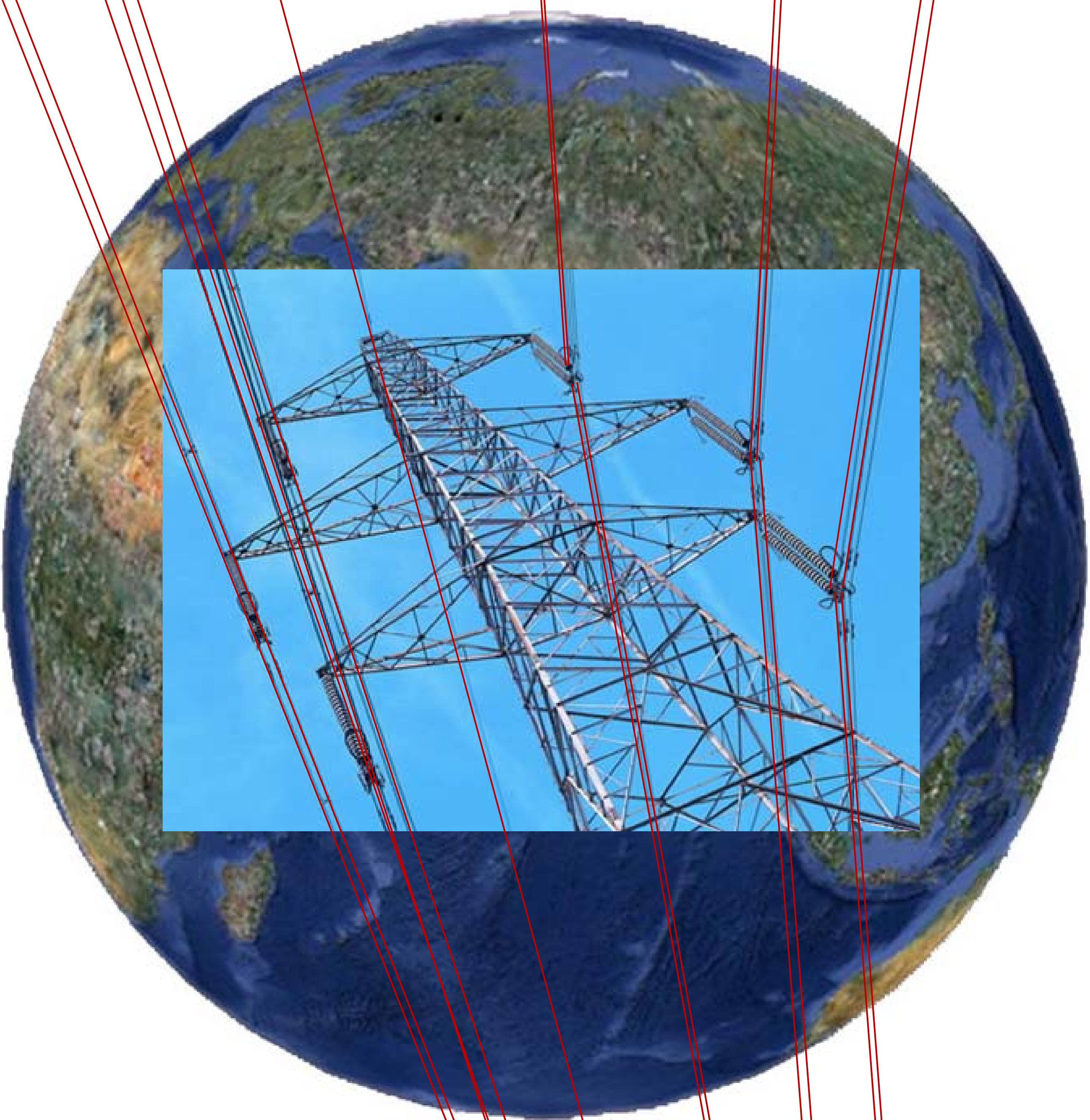
Inventory of country specific electricity in LCA

- consequential and attributional scenarios

Methodology report v2



by Jannick H Schmidt*, Mikkel Thrane**, Stefano Merciai* and Randi Dalgaard*

**2.-0 LCA consultants, Aalborg, Denmark*

*** Danisco, Copenhagen, Denmark*

Preface

Together with Danisco, 2.-0 LCA has initiated the current electricity project with the aim of establishing consequential and attributional LCIs on electricity in different countries. The project is established as a club to which anyone can subscribe. The LCA electricity club is administrated by 2.-0 LCA consultants. For more information and subscription, please contact 2.-0 LCA consultants:
http://www.lca-net.com/projects/electricity_in_lca/

Recommended reference to this report:

Schmidt J H, Merciai S, Thrane M and Dalgaard R (2011), *Inventory of country specific electricity in LCA – Consequential and attributional scenarios*. *Methodology report v2*. 2.-0 LCA consultants, Aalborg
http://www.lca-net.com/projects/electricity_in_lca/

Aalborg, 9 September 2011

Published by:
2.-0 LCA consultants

Contents

1 **Introduction** ... 7

2 **Goal and scope definition** ... 9

2.1 ISO standard on life cycle assessment ... 9
2.2 Purpose of the study ... 9
2.3 Functional unit ... 9
2.4 Market delimitation; geographical delimitation and market segments ... 9
Geographical delimitation ... 9

Market segments ... 10

2.5 Product system ... 11
2.6 Cut-off criteria ... 12
2.7 Modelling assumptions ... 12
2.8 Scenario switch in SimaPro and ecoinvent v2.2 ... 12
Scenario switches in SimaPro ... 12

Implementation of switches on electricity in ecoinvent v2.2 ... 13

3 **Consequential and attributional modelling assumptions** ... 15

3.1 Definition of consequential and attributional modelling assumptions ... 15
Attributional modelling ... 15

Consequential modelling ... 15

3.2 Interpretation of LCA results obtained by consequential vs. attributional modelling ... 15
3.3 Application of consequential and attributional modelling assumptions ... 16
Attributional modelling of electricity use ... 16

Consequential modelling of electricity use ... 16

Three consequential scenarios ... 17

4 **Inventory data for transmission and distribution** ... 19

5 **Inventory of biomass production and burning** ... 21

6 **References** ... 25

1 Introduction

The modelling of electricity in life cycle inventory has given rise to debates during the last decades. Significant issues in the debate are discussions on geographical delimitation of electricity markets, the question of whether constrained suppliers should be included, the modelling of co-products if electricity is co-produced with electricity, and in cases where the marginal supply is identified; the question whether the modelling should represent the short-term/production marginal or the long-term/build marginal. Many of the issues listed above are related to the different modelling assumptions applied in consequential and attributional modelling.

This methodology report provides qualified answers and recommendations regarding the above-mentioned issues. A generalized inventory methodology is outlined which enables for the application of consequential as well as attributional modelling assumptions. The inventory methodology described in the current report is applied to national and regional life cycle inventories. These inventories are presented in separate reports.

2 Goal and scope definition

2.1 ISO standard on life cycle assessment

In general the ISO 14040 and 14044 standards on life cycle assessment (LCA) are followed. However, since the current study is an inventory study, and not a full LCA, not all aspects of the standard are considered. The major items of the ISO 14044 which are not included are:

- The inventory study has not undergone a critical review
- The study does not include the impact assessment and interpretation phases of an LCA

2.2 Purpose of the study

The purpose of the study is to provide consistent, scientifically sound country and region specific electricity inventories. This includes the option to apply different consequential scenarios and an attributional scenario to the inventory data.

The presented methodology and country and region-specific inventories of electricity (in the separate inventory reports) are intended to be used in the following ways:

- The inventories include life cycle inventory (LCI) results as well as life cycle impact assessment (LCIA) results for selected LCIA methods. These results can be used directly in other LCA studies.
- The inventories are presented with links to the ecoinvent database (for combustion of fuels, upstream emissions etc.). However, other LCI databases can be used as well. Thus, the inventories can be implemented in any LCA software and linked to any LCI database. The LCIs in the inventory reports are documented in a logical, consistent and transparent way, so that the implementation in LCA software and linking to other LCA databases should be relatively straightforward.
- Beside the inventory reports, the inventories are also provided as CSV-files that can be imported directly into SimaPro where it links to the ecoinvent database.

2.3 Functional unit

The functional unit of all inventories is 1 kWh electricity. Inventory data are provided at different stages in the life cycle of electricity: electricity mix at: 1) power plant, 2) high voltage, 3) medium voltage, and 4) low voltage. The different stages or markets for electricity are described further in **section 2.4 'Market delimitation'**.

2.4 Market delimitation; geographical delimitation and market segments

Geographical delimitation

Electricity markets are regarded as national markets, where the national electricity production plus import are regarded as the relevant suppliers. The fact that a national geographical delimitation is applied is justified by the fact that countries have national energy plans and regulation. Also, in the long-term, national domestic electricity production typically changes at the same rate as domestic demand. Of course there may be exceptions from the above-mentioned national geographical delimitation. In these cases, the presented inventory methodology can be applied to the relevant market, but the default assumption for all inventories is that a national geographical delimitation is the most relevant.

Sometimes when conducting life cycle inventories, knowledge on the geographical location (which country) of a certain supplier that uses electricity is not available. This is most often valid for suppliers several steps upstream in the supply chain. Also, some LCAs are carried out as averages of a region that is larger than a country. In these cases, it is relevant to consider average markets of larger regions, e.g. Europe or the world.

Market segments

Electricity can be obtained at different markets within each geographical market. In each region distinction is made between four markets. These are explained in **Table 1**.

Table 1: Explanation of different electricity market segments.

Market segments	Explanation of market segments
Electricity, low voltage, at grid	Household and service industry uses of electricity
Electricity, medium voltage, at grid	Production industry’s use of electricity
Electricity, high voltage, at grid	Few, butvery energy intensive or remote activities, such as electric trains and mining activities
Electricity mix	Electricity at production. This is actually not a real market because activities cannot purchase electricity directly from this market. The ‘electricity mix’ market is typically affected when activities co-produce electricity as a dependent co-product, and when this is modelled applying substitution.

2.5 Product system

Figure 1 illustrates a generalised product system that applies to any country or region included in the study.

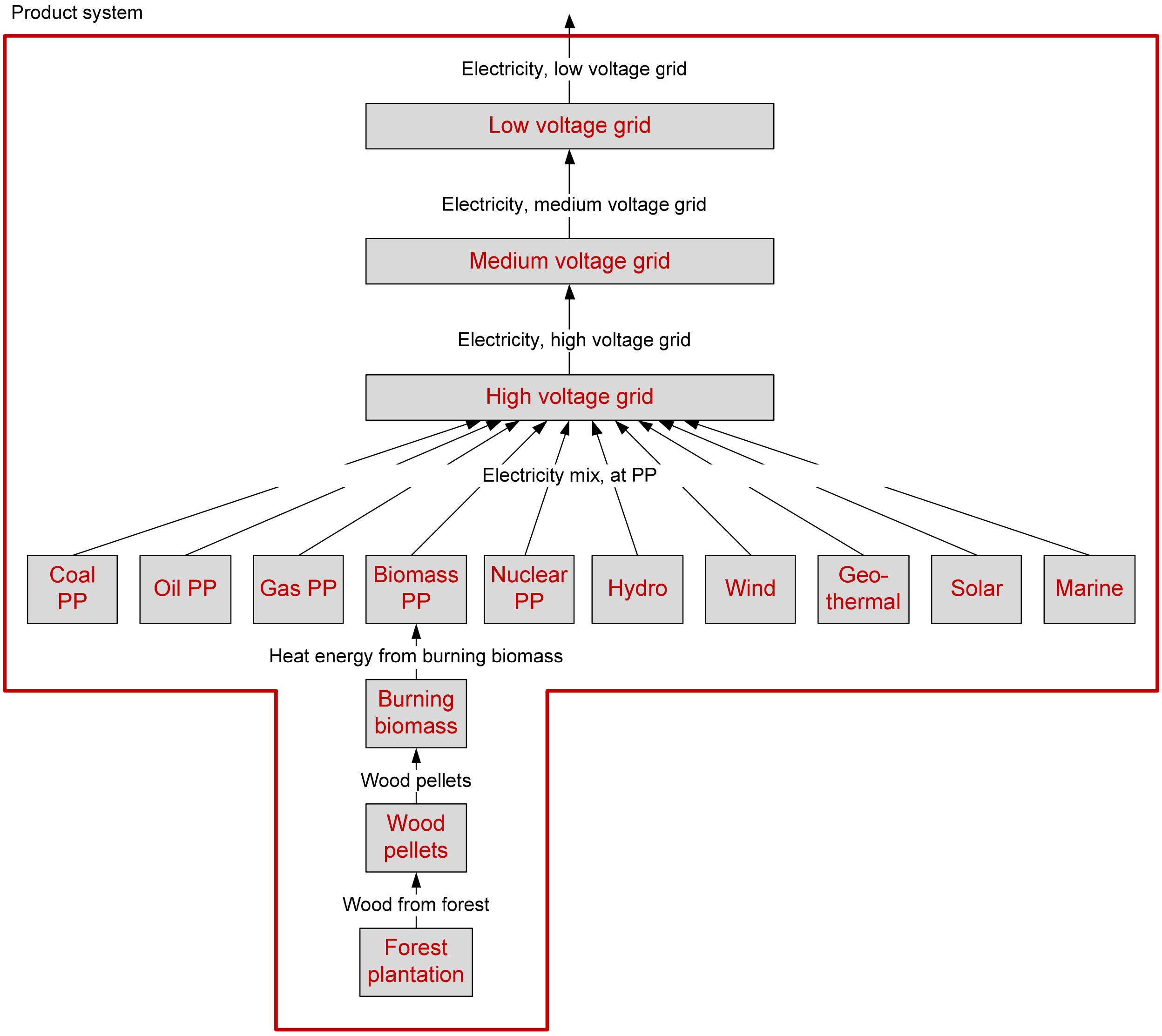


Figure 1: Overview of the product system for which data are collected. All shown activities (grey boxes) are linked to upstream activities, but these are not shown here. LCI data for upstream data (production of fuels etc.) are based on the ecoinvent database. PP: Power plant.

The current study provides an inventory of each of the activities (the grey boxes in **Figure 1**) for each country or region. However, the three upstream activities of the 'Biomass PP' are generic to all countries, and hence the inventory of these activities is presented in the current methodology report. The reason that these are specifically inventoried, while the other upstream activities are not, is that the available LCI data on forestry products and biomass electricity in ecoinvent are all allocated and thus, they are not compatible with the modelling assumptions applied in the current study.

2.6 Cut-off criteria

The inventories include all major physical flows from resource extraction of fuels to power plant emissions and treatment of waste such as slag and ashes etc. Capital goods, infrastructure, and maintenance of machinery are included.

Inputs related to overhead are not included. This includes the following physical products: lighting and heating of buildings, furniture, computers, printers, paper and pencils etc. Further, service inputs are not included: cleaning, marketing, accounting, business travel, postal services, communication, banking services etc.

In general, the current study applies the same cut-off criteria as the electricity activities in ecoinvent.

2.7 Modelling assumptions

The inventories are carried out using the following modelling assumptions:

- **Consequential future:** Represents the long-term marginal supply based on information on electricity capacity and generation for the years 2008 (statistical data) and 2020 (outlook data).
- **Consequential historical:** Represents the long-term marginal supply based on information on electricity capacity and generation in year 2000 and 2008 (all statistical data). The purpose of this scenario is to provide a consequential scenario based on real statistical data. It can be applied for sensitivity analysis purposes or if outlook data for the future scenario are not considered reliable.
- **Consequential coal:** This scenario applies 100% coal based electricity in all countries and regions. The purpose of this scenario is to provide a conservative scenario that can be applied for sensitivity analysis purposes.
- **Attributional:** This scenario applies the current (year 2008) electricity production mix to all countries and regions.

The specific modelling assumptions in the above-listed scenarios are described in **Section 3.3 'Application of consequential and attributional modelling assumptions**'.

2.8 Scenario switch in SimaPro and ecoinvent v2.2

If the electricity inventory CSV-file is imported into SimaPro, the applied modelling assumption can be changed by using a switch parameter.

Scenario switches in SimaPro

In order to facilitate scenario analysis and sensitivity analyses, the electricity scenarios described in this chapter are implemented in SimaPro via switches. The following switches are defined:

- **clca_future** [1= on and 0 = off]
- **clca_historical** [1= on and 0 = off]
- **clca_coal** [1= on and 0 = off]
- **alca** [1= on and 0 = off]

It should be noted that only one of the above-mentioned switches are allowed to be turned on at a time.

Implementation of switches on electricity in ecoinvent v2.2

Almost all ecoinvent processes refer to European average technology (termed 'RER' in ecoinvent), i.e. the processes also link to average European electricity. In ecoinvent this electricity process is 'Electricity, production mix UCTE/UCTE U'. Therefore, in order to implement changes in the electricity for all ecoinvent processes only this specific electricity process needs to be changed. This is done by implementing the database parameters listed above in the ecoinvent library project in the process 'Electricity, production mix UCTE/UCTE U'.

3 Consequential and attributional modelling assumptions

3.1 Definition of consequential and attributional modelling assumptions

Attributional modelling

Attributional modelling is characterised by including market averages, i.e. national current electricity mix including imports, and by modelling multiple-output activities by applying allocation factors.

Consequential modelling

Consequential modelling is characterised by excluding constrained suppliers in the electricity mix and by avoiding allocation by substitution (Weidema et al. 2009). A major problem with the attributional method (described above), is that it includes all suppliers to the electricity market, including those who are constrained. A constrained supplier is characterised by not being able to respond to changes in demand for electricity. Using attributional modelling thereby includes suppliers that will not be affected by a decision supported by the LCA. This may potentially result in misleading decision support and eventually in undesirable decisions: If country x has a 10 times smaller impact than country y – the result of the LCA might be that more production is moved to country x. But in many cases, the low emission figure for country x, is a result of historical investments in e.g. hydropower, which in many cases cannot be expanded further due to natural limits. It is more relevant how investments are carried out today, and in the future – and how that is related to the demand for electricity. In other words, it is more relevant to identify the most likely affected energy suppliers – i.e. the long-term marginal energy suppliers. Marginal supply can be identified in the short term as well as in the long-term. Since LCA generally is used for decision support related to decisions that have long-term implications, the relevant marginal supply is the long-term marginal supply. Long-term marginal supply is sometimes referred to as the 'build-marginal', i.e. the technology of the capacity to be installed next.

Co-product allocation is avoided by substitution, where 100% of the impact is allocated to the determining co-product, and the substituted products related to the depended co-products are subtracted. The consequential modelling assumption is based on causality and the principle of mass and energy balance/conservation. The consequential modelling approach is described in detail in Weidema et al. (2009), Suh et al. (2010), and Weidema and Schmidt (2010).

3.2 Interpretation of LCA results obtained by consequential vs. attributional modelling

The interpretation of results calculated with the attributional and the consequential approach is described in the following. In the description it is presumed that the LCA results are intended for use in a decision context. Decisions always concern a choice between alternatives, i.e. to keep the existing system, or to choose alternative A, B, C etc. In this context, the relevant LCA results should be used to say something about the difference between the alternatives, thus they should represent the effects of a change in demand, production etc.

Results calculated by use of attributional modelling assumptions can be interpreted as if the difference between the considered alternatives can be represented by an average of the current suppliers. Since multiple-output activities are allocated, it is inherently assumed that the production volume of the activity is determined by the demand for all co-products in a ratio corresponding to the applied allocation principle (economic turnover, mass, energy content etc.).

Results calculated using the consequential modelling assumptions can be interpreted as if the difference between the considered alternatives can be represented by the identified likely changes in the product system caused by a change in demand.

3.3 Application of consequential and attributional modelling assumptions

Attributional modelling of electricity use

The attributional scenario applies a national average electricity supply, i.e. average of domestic generation plus import.

The current version of the electricity model does not consider electricity co-produced with heat in the national electricity mix. Hence, all electricity is modelled as if it was produced without co-production of heat, i.e. in pure electricity plants. It should be noted that this limitation only applies to the attributional scenario because consequential modelling does not include constrained supplies. Electricity co-produced with heat will always be either determined by the demand for heat (i.e. CHP plants using back-pressure mode) or it can be independently varied from the heat generation (i.e. in extraction plants). In the latter case a change in the production of electricity with constant heat generation corresponds to electricity production without co-production of heat (i.e. power plant using condensation mode).

Consequential modelling of electricity use

Identifying the actual affected electricity supplier in the long-term as a consequence of a change in demand for electricity often has significant effects on the results of the LCA but it is also related to uncertainties. Some studies have identified coal and gas as the affected suppliers in Denmark/Nordel grid (Lund et al. 2010; Weidema 2003). However, the identification of marginal electricity in these studies is problematic because:

- Lund et al. (2010) identifies the short-term marginal and not the long-term marginal. It is the latter which is relevant in consequential modelling except in a few special cases (Weidema et al. 2009)
- Weidema (2003) presumes that installation of electricity generation capacity takes place on an unconstrained market (except for wind power and nuclear), i.e. that the marginal producer can be determined as minimizing the long-term expected costs. However, the actual developments in electricity markets have shown that this assumption does not reflect reality.

It can be argued that all suppliers in the electricity capacity market are regulated since the installation of new electricity capacity is highly regulated in energy plans (and subsequent investment decisions) as well as renewable energy and GHG-emissions targets set out in e.g. the EU renewable energy directive (Directive 2009/28/EC) and the Kyoto Protocol. . Furthermore, this regulation is considered as being national; generally it is assumed that energy plans strive towards supplying a country's own electricity demand, without relying on imports.

Based on the above-mentioned arguments, the long-term marginal electricity suppliers in a country are defined as the national mix of planned/predicted new installation during a specified period of time.

The default assumption is that there are no constrained suppliers. A screening is made to check for such constraints. The relevant constraints that are screened for are:

- suppliers/technologies that face a decreasing trend are assumed to be phased out or to be uncompetitive, i.e. they are constrained;
- constrained availability of natural resources, e.g. the potential to install more hydro power capacity; and
- for CHP plants, the demand for the main products put a constraint on the dependent by-product, electricity.

Three consequential scenarios

Two scenarios are defined based on the above definition of the long-term marginal electricity suppliers:

1. clca_future: The change in power generation is based on the difference between 2008 and 2020, i.e. between current/recent mix and expected mix in 2020. The expected mix is identified in national energy plans.
2. clca_historical: The change in power generation is based on the difference between 2000 and 2008, i.e. it is purely based on historical statistical data.

In the clca_future scenario, a time frame from 2008 to 2020 is chosen because of data availability; energy plans and outlook for this period exist for most countries and they are considered as being less uncertain than energy outlooks that reach further out into the future.

Besides the two first consequential scenarios, which comply with the definition of the long-term marginal electricity suppliers as outlined above, a 100% coal based electricity scenario is also provided:

3. clca_coal: The power generation is based on 100% coal.

4 Inventory data for transmission and distribution

Transmission and distribution of electricity is modelled using existing ecoinvent processes. These processes are:

- Electricity, low voltage, at grid/[country] U
- Electricity, medium voltage, at grid/[country] U
- Electricity, high voltage, at grid/[country] U

For those countries where ecoinvent processes do not exist, the ecoinvent processes for UCTE are used and then modified to reflect country specific grid losses.

Table 2: Overview of the applied distribution losses in the different electricity mixes.

Country	Loss in the grid (% of input):				Data source for grid loss
	High voltage	Medium voltage	Low voltage	Total	
BE - Belguim	0.8%	0.7%	6.3%	**7.9%**	ecoinvent (2010)
BR - Brazil	1.6%	2.3%	20.3%	**25.0%**	ecoinvent (2010)
CZ - Czech Republic	1.1%	1.2%	11.1%	**13.6%**	ecoinvent (2010)
CN - China	0.9%	1.0%	21.3%	**23.6%**	ecoinvent (2010)
DE - Germany	0.9%	0.9%	8.2%	**10.2%**	ecoinvent (2010)
DK - Denmark	0.9%	0.7%	7.0%	**8.7%**	ecoinvent (2010)
FI - Finland	0.7%	0.7%	9.0%	**10.6%**	ecoinvent (2010)
FR - France	1.0%	1.0%	9.1%	**11.2%**	ecoinvent (2010)
IN - India	1.8%	2.0%	18.5%	**23.1%**	The total distribution loss at 23.1% is obtained from IEA (2011). This is distributed over the three distribution steps assuming the same relative distribution as Europe, RER.
Europe, RER	1.0%	1.1%	10.0%	**12.3%**	ecoinvent (2010)
Europe, UCTE	1.0%	1.1%	10.0%	**12.4%**	ecoinvent (2010)
MY - Malaysia	1.0%	1.1%	9.7%	**12.0%**	The total distribution loss at 12% is estimated. Data from IEA (2011) show unrealistic low losses at 2-3%. The 12% loss is distributed over the three distribution steps assuming the same relative distribution as Europe, RER.
MX – Mexico	1.3%	1.5%	13.2%	**16.4%**	The total distribution loss at 16.4% is obtained from IEA (2011). This is distributed over the three distribution steps assuming the same relative distribution as Europe, RER.
US - United States	1.0%	1.0%	7.4%	**9.5%**	ecoinvent (2010)
GLO - World	0.7%	0.7%	6.7%	**8.3%**	The total distribution loss at 8.3% is obtained from IEA (2011). This is distributed over the three distribution steps assuming the same relative distribution as Europe, RER.

5 Inventory of biomass production and burning

This section presents a life cycle inventory of the three activities related to the burning of biomass in **Figure 1**. Since the market for wood pellets is considered global, the activity is carried out applying a global geographical system delimitation.

Table 3 presents the inventory of the burning of wood pellets. As specified in the table text, the data are based on ecoinvent. The only modifications are the application of new inventory data for wood pellets (see **Table 4**) and a changed electricity mix for the input of electricity; changed from European mix to global mix.

Table 3: Inventory data for burning biomass (wood pellets) for electricity generation. Inputs and outputs are based on 'Pellets, mixed, burned in furnace 50kW/CH U' (ecoinvent 2010).

Flows	Wood pellets burned in power plant	Unit	LCI data, reference to ecoinvent (2010)
Outputs			
Wood pellets burned in pp	1	MJ	Reference flow
Inputs			
Wood pellets	0.0533	kg	See **Table 4**, Energy density is 18.8 MJ/kg dry matter (Prapaspongsa et al. 2010, p 50)
Electricity	0.00417	kWh	'Electricity, medium voltage, at grid/GLO U' (Merciai et al. 2011)
Furnace, pellets	1.5E-7	p	'Furnace, pellets, 50kW/CH/I U'
Transport	0.00587	tkm	'Transport, lorry 20-28t, fleet average/CH U'
Disposal of wood ash to land farming	0.000238	kg	'Disposal, wood ash mixture, pure, 0% water, to landfarming/CH U'
Emissions			
Emissions	1	MJ	Emissions are obtained from 'Pellets, mixed, burned in furnace 50kW/CH U'

Table 4 presents the inventory data for the production of wood pellets. The data are based on Prapaspongsa et al. (2010).

Table 4: Inventory data for wood pellet production. Data are obtained from Prapaspongsa et al. (2010, p 52). The use of woodfuel for drying is obtained from Magelli et al. (2009).

Flows	Wood pellets	Unit	LCI data, reference to ecoinvent (2010)
Outputs			
Wood pellets	1	kg DM	Reference flow
Inputs			
Wood, feedstock	1	kg DM	See **Table5**
Wood, as fuel for drying	0.187	kg DM	3.168 MJ/kg pellet * 1/0.9 kg pellet/kg DM * 1/18.8MJ/kg DM = 0.187 kg DM. LCI data: See **Table5**
Diesel incl. combustion	0.208	MJ	'Diesel, burned in building machine/GLO U'
Electricity	0.266	kWh	'Electricity, medium voltage, at grid/GLO U' (Merciai et al. 2011)
Natural gas incl. combustion	3.17	MJ	'Natural gas, burned in industrial furnace >100kW/RER U'
Wood pellet plant	1.55E-11	p	'Wood pellet manufacturing, infrastructure/RER/I U'
Emissions			
Emissions from burning wood	0.187	kg DM	Emissions from bottom of **Table 3**are applied. Conversion from MJ wood to kg DM wood using the energy density at 18.8 MJ/kg DM

According to Reinhard et al. (2010) the marginal source of unspecified hard wood and soft wood can be identified as eucalyptus wood from plantations in Brazil and pine wood from plantations in Chile respectively. Due to lack of data, it is assumed that the marginal source of wood for wood pellets is composed of 50% hardwood and 50% softwood. The data are based on Prapaspongsa et al. (2010).

Table5: Inventory data for forest plantation for biofuel production: Eucalyptus in Brazil and pine in Chile. The inventory data are shown for 1 ha yr. Data are obtained from Prapaspongsa et al. (2010, p 50-51).

Flows	Eucalyptus, Brazil	Pine, Chile	Unit	LCI data, reference to ecoinvent (2010)
Properties of wood and plantation				
Wood density	495	399	kg DM/m^3	-
Energy density	18.8	18.8	MJ/kg DM	-
Rotation time	7	27.5	years	-
Outputs				
Wood	20,500	8,780	kg DM	Reference flow
Inputs				
Diesel + combustion	4077	4077	MJ	'Diesel, burned in building machine/GLO U'
N-Fertiliser, as N	10.2	10.2	kg	'Ammonium nitrate, as N, at regional storehouse/RER U'
P-Fertiliser, as P_2O_5	17.1	17.1	kg	'Triple superphosphate, as P2O5, at regional storehouse/RER U'
K-Fertiliser, as K_2O	12.3	12.3	kg	'Potassium chloride, as K2O, at regional storehouse/RER U'
Glyphosate	3.16	3.16	kg	'Glyphosate, at regional storehouse/RER U'
Insecticide	0.143	0.143	kg	'Insecticides, at regional storehouse/RER U'
Limestone	143	143	kg	'Limestone, milled, loose, at plant/CH U'
Lubricant oil + decomposition (C)	3.27	3.27	kg	'Lubricating oil, at plant/RER U'
Land tenure, forest land not fit for agr.	1	1	ha yr	Schmidt et al. (2011)
Emissions				
CO_2 to air	10.2	10.2	kg	The carbon content of lubricating oil (85% of oil) is emitted as CO_2 when the lubricant decomposes = 85% of 3.27 kg * 44/12 kg CO2/kg C = 10.2 kg CO_2
N_2O to air	0.160	0.160	kg	N_2O-N is equal to 0.01 of N applied as mineral fertiliser (IPCC 2006, chapter 11, table 11.1). N_2O to N_2O-N ratio is 44/28.
P_2O_5 to water	0.410	0.410	kg	-
Pesticides	-	-	kg	Not included

6 References

Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 001/77/EC and 2003/30/EC. European Parliament and of the Council

Ecoinvent (2010),Ecoinvent data v2.2.Final reports Ecoinvent v2.2 No. 1-25. Swiss Centre for Life Cycle Inventories, Dübendorf. The inventory data and reports are available in the LCA pc-software SimaPro 7.3.

IPCC (2006), 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H S, Buendia L, Miwa K, Ngara T and Tanabe K (eds). The Intergovernmental Panel on Climate Change

IEA (2011), IEA Statistics, Statistics by Product, Electricity/Heat. International Energy Agency http://www.iea.org/stats/prodresult.asp?PRODUCT=Electricity/Heat (Accessed during 2010-2011)

Lund H, Mathiesen BV, Christensen P, and Schmidt JH (2010): Energy system analysis of marginal electricity supply in consequential LCA. International Journal of Life Cycle Assessment 15:260-271

Magelli F, Boucher K, Bi H T, Melin S and Bonoli A (2009), An environmental impact assessment of exported wood pellets from Canada to Europe. Biomass and Bioenergy 33, 434-441.

Merciai S, Schmidt J H and Dalgaard R (2011), Inventory of country specific electricity in LCA - World. Inventory report v2. 2.-0 LCA consultants, Aalborg http://www.lca-net.com/projects/electricity_in_lca/

Prapaspongsa T, Kørnøv L and Schmidt J H (2010), Life cycle assessment of biomass power production in Denmark and UK. A background report for impact assessment on increased use of biomass in DONG Energy's power and heat production.

Reinhard J, Weidema B P and Schmidt J H (2010), Identifying the marginal supply of pulp wood. 2.-0 LCA consultants, Aalborg, Denmark. Accessed October 2010: http://www.lca-net.com/files/Reinhard_et_al_(2010)_Identifying_the_marginal_supply_of_pulp_wood.pdf

Schmidt J H, Reinhard J, and Weidema B P (2011), Modelling of indirect land use changes in LCA. report v2. 2.-0 LCA consultants, Aalborg

Suh S, Weidema B, Schmidt J H and Reinout H (2010), Generalized Make and Use Framework for Allocation in Life Cycle Assessment. Journal of Industrial Ecology 14(2): 335-353<DOI: 10.1111/j.1530-9290.2010.00235.x>

Weidema B P (2003), Market information in life cycle assessment. Environmental Project No 863.Danish Environmental Protection Agency, Copenhagen. Accessed September 2010: http://www.miljoestyrelsen.dk/udgiv/Publications/2003/87-7972-991-6/pdf/87-7972-992-4.pdf

Weidema B P, Ekvall T, Heijungs R (2009), Guidelines for applications of deepened and broadened LCA. Deliverable D18 of work package 5 of the CALCAS project. http://fr1.estis.net/includes/file.asp?site=calcas&file=7F2938F9-09CD-409F-9D70-767169EC8AA9

Weidema B P, J H Schmidt (2010), Avoiding allocation in life cycle assessment revisited. Column for Journal of Industrial Ecology 14(2):192-195<DOI: 10.1111/j.1530-9290.2010.00236.x>