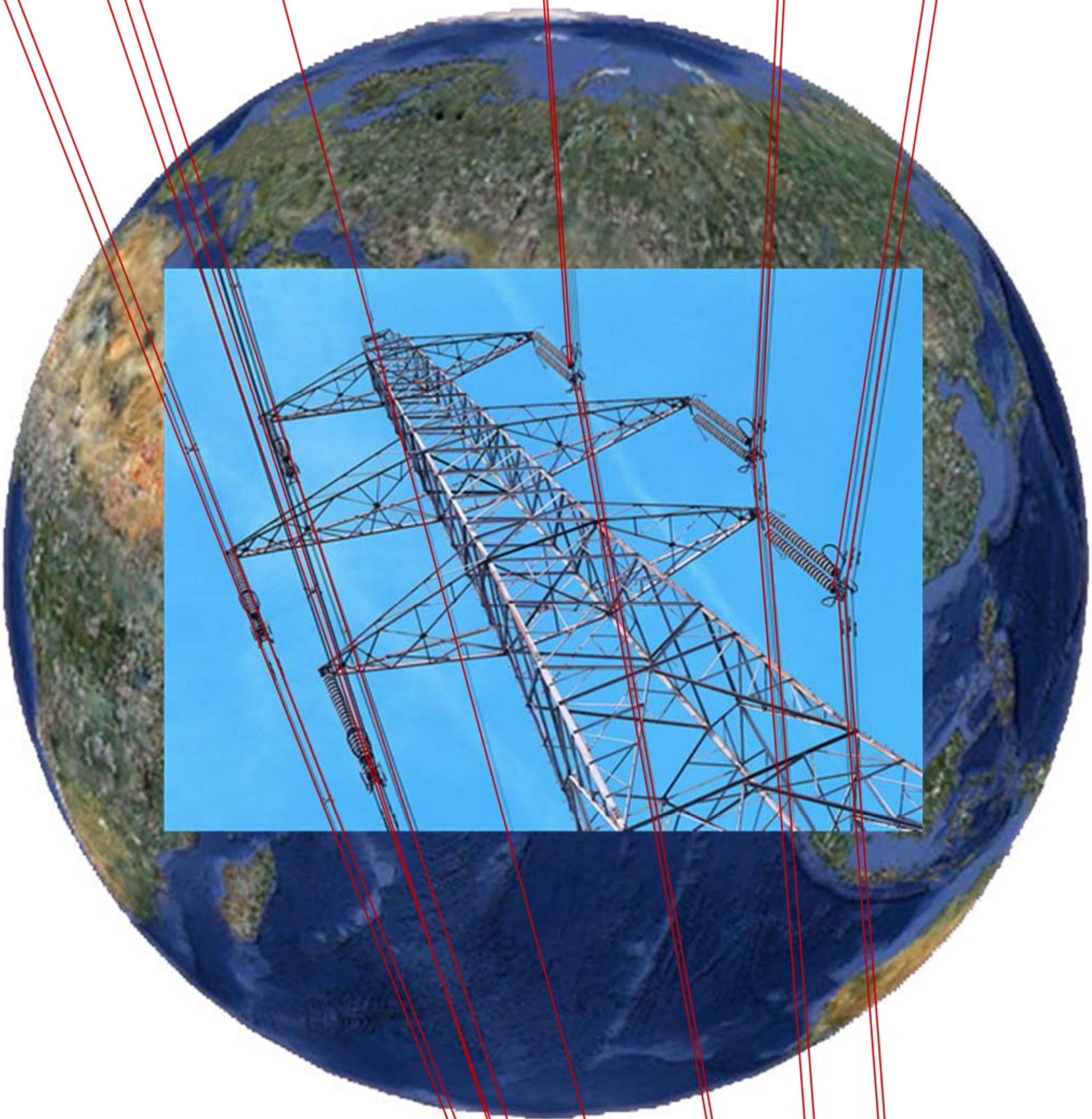
Inventory of country specific electricity in LCA
- consequential scenarios

Version 3.0



by Ivan Muñoz, Jannick Schmidt, Marie de Saxcé, Randi Dalgaard and Stefano Merciai
2.-0 LCA consultants, Aalborg, Denmark

2.-0 LCA consultants

Preface

In 2011, co-working with DuPont (former Danisco), 2.-0 LCA consultants initiated this electricity project with the aim of establishing consequential life cycle inventories on electricity in different countries. The project is established as a club to which anyone can subscribe. The LCA Energy Club is administrated by 2.-0 LCA consultants. For more information, please contact 2.-0 LCA consultants: http://lca-net.com/clubs/energy/

Recommended reference to this report:

***Muñoz I, Schmidt J H, de Saxcé M, Dalgaard R, Merciai S* (2015)**, *Inventory of country specific electricity in LCA - consequential scenarios*. *Version 3.0.* Report of the 2.-0 LCA Energy Club. *2.*-0 LCA consultants, Aalborg http://lca-net.com/clubs/energy/

Aalborg, August 2015

Published by:
2.-0 LCA consultants

Contents

Acronyms and abbreviations

Countries/regions

BE	Belgium
BR	Brazil
CH	Switzerland
CL	Chile
CN	China
CZ	Czech Republic
DE	Germany
DK	Denmark
ES	Spain
EU28	European Union
FI	Finland
FR	France
GB	Great Britain
GLO	World
ID	Indonesia
IN	India
IPCC	Intergovernmental panel on climate change
MRO	Midwest Reliability Organization
MX	Mexico
MY	Malaysia
PL	Poland
RoW	Rest of the world
SE	Sweden
UK	United Kingdom
US	United States
WECC	Western Electricity coordinating Council

Other

C	Carbon
CHP	Combined heat and power
CLCA	consequential LCA
Conseq	Consequential
CSV	Comma-separated values
DM	Dry matter
GHG	Greenhouse-gas emissions
GWP	Global warming potential
HVolt	High voltage
IEA	International Energy Agency
iLUC	Indirect land use change
ISO	International Standards Organization

kW	Kilowatt
kWh	Kilowatt-hour
kWp	Kilowatt-peak
LCA	Life cycle assessment
LCI	Life cycle inventory
LVolt	Low voltage
MJ	Mega Joule
MVolt	Medium voltage
NPP_0	Net primary production
OECD	Organization for Economic Co-operation and Development
p	One unit of a product or equipment
PP	Power plant
TWh	Terawatt-hour

1 Introduction

The modelling of electricity in life cycle inventory (LCI) has risen 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 heat 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 report provides qualified answers and recommendations regarding the above-mentioned issues. A generalized inventory methodology is outlined which enables for the application of consequential modelling assumptions. The inventory methodology described in the current report is applied to national and regional life cycle inventories.

Do not forget to read the Q&A in chapter 8.

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 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 the linking to other LCA databases should be relatively straightforward.
- Besides 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 About attributional electricity modelling

In previous versions of this project also attributional electricity production profiles were considered, based on statistical data. However, given that the ecoinvent v3 database includes attributional electricity mixes and that the geographical coverage of world electricity production has increased in ecoinvent v3, we recommend to use the latter directly. As a consequence, attributional modelling is no longer covered by the Energy Club. There are only three exceptions to this:

- Electricity mix for Europe (EU28)
- Electricity mix for the United States (US)
- Electricity mix for the world (GLO)

For these three regions the ‘e1’ switch (see section 2.9) reflects an average electricity mix. This has been done due to the fact that currently ecoinvent v3 does not include electricity mixes for these regions. Further details about these average electricity mixes can be found in the respective parts of chapter 1.

2.4 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 2.5.

2.5 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, but very 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.

2.6 Product system

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

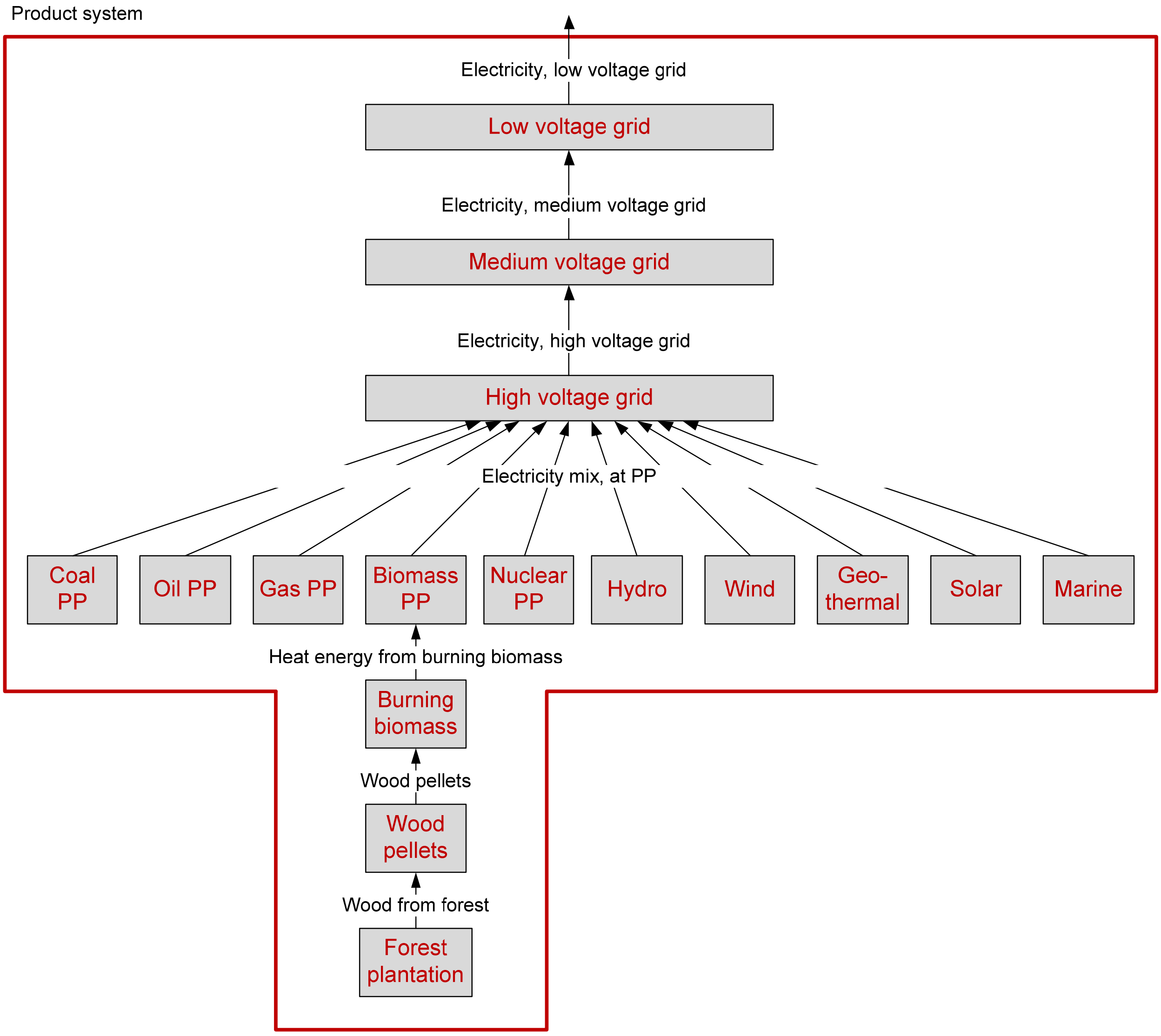


Figure 1: Overview of the product system for which data are collected. All shown activities (grey boxes) are linked to upstream activities, but these are not shown here. LCI data for upstream data (production of fuels etc.) are based on the ecoinvent database. PP: Power plant.

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, whereas the other processes are directly modelled using ecoinvent.

2.7 Cut-off criteria

The inventories generally follow the same system boundaries as ecoinvent v3 (Weidema et al. 2013). However, for one topic, the level of completeness is higher than for ecoinvent: the inventories provide the option to link to a model for indirect land use changes (relevant for biofuel-based electricity): see section 2.10.

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.

2.8 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 or 2012 (statistical data) and 2020 (outlook data). This scenario is the recommended default scenario.
- **Consequential historical:** Represents the long-term marginal supply based on information on electricity capacity and generation in year 2000 and 2008 or 2012 (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.

The specific modelling assumptions in the above-listed scenarios are described in Section 3.3. Furthermore, there is a Q&A section in chapter 8.

2.9 Scenario switches in SimaPro

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

The implementation of clca scenarios in SimaPro is carried out by means of parameters. Four database parameters have been created in SimaPro. They are defined to take only the discrete values '1' or '0', where only one of the parameters at a time can have the value '1'. In practice,this constitutes a switch where the value '1' switches on the corresponding parameter everywhere in the SimaPro database, whereas the value '0' maintains the remaining three parameters switched off.

The switches defined in ecoinvent v3 are:

- e1: switches on the default ecoinvent v3 electricity scenario.
- e2: switches on the clca_future scenario.
- e3: switches on the clca_historical scenario.
- e4: switches on the clca_coal scenario.

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

2.10 Indirect land use changes (iLUC)

Indirect land use change (iLUC) is included in this project only for electricity production from biomass (see section 4.6, using the model developed by Schmidt et al. (2015). However, the use of the iLUC model is controlled by the use of parameter 'switches', by which it can be turned on and off, depending on the need to include iLUC or not in the calculations. It should be noted that access to the iLUC model requires a membership of the iLUC club (http://lca-net.com/clubs/iluc/). Users of the electricity date, who have not subscribed to the iLUC club, can see the iLUC activities in the life cycle inventory, but these are empty, i.e. no links to other activities or emissions.

3 Consequential modelling assumptions

3.1 Definition of consequential modelling assumptions

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 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 modelling

The interpretation of results calculated with 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 unconstrained suppliers most likely to respond to a change in demand.

3.3 Application of consequential modelling assumptions

Identifying the actual affected electricity supplier, in long-term, as a consequence of 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) identify 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 in 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 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;
- for CHP plants, the demand for the main products put a constraint on the dependent by-product, electricity.

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

1. clca_future (switch e2): 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 (switch e3): 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 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.

Also, do not forget to read the Q&A in chapter 8.

3.4 A critique of consequential electricity mixes in ecoinvent v3

In its version 3, ecoinvent has for the first time included a consequential system model in the database, called 'Substitution, consequential, long-term'. This system model includes electricity profiles for countries and regions. Given this new development, one could question the necessity of developing alternative consequential electricity mixes as in the current report. In this section we identify the problems with the way ecoinvent has implemented consequential modelling in its electricity mixes, and we provide the arguments why we recommend to using the method proposed in the current report.

Generally, ecoinvent has identified the marginal mix by first identifying the current electricity mix for the country/region, and secondly by excluding those suppliers who meet any of the following requirements:

- Electricity is not the reference flow, such as in electricity from CHP.
- The technology has not been classified as modern. Only a few technologies have been classified as modern.

In practice, consequential electricity mixes in ecoinvent, too often, contain constrained suppliers. As an example, hydropower is considered as a supplier in Norway, even though this technology cannot develop further in this country due to natural constraints.

Another flaw in the way ecoinvent built these electricity mixes is that the share of different technologies in the current mix determines the proportion in the marginal mix. In many cases, this results in coal and gas often playing a major role, despite the fact that many countries are actually reducing or partly phasing out these technologies. As an example all EU countries have made explicit commitments in this direction (see EU's renewable energy national action plans: http://ec.europa.eu/energy/en/topics/renewable-energy/national-action-plans). The effect of taking this approach is rather dramatic for many countries, for example Denmark, where the ecoinvent electricity mix shows that coal accounts for 70% of the mix, in spite of the country's decision to phase out coal (future prediction), and the fact that the share of coal has been decreasing during the last decade (historical fact).

Though, it must be highlighted that the ecoinvent centre openly admits these limitations. In Bauer (2013), ecoinvent states that current implementation in the database can lead to unrealistic consequential electricity profiles in some regions, and it is recommended for users to create their own datasets according to more specific information concerning constrained/unconstrained power generation in specific geographical regions.

4 Implementation in ecoinvent v3

Originally, the electricity inventories developed within this project were implemented in ecoinvent v2. The new version 3 of ecoinvent introduced substantial changes that needed to be dealt with. This section describes the procedure followed to adapt the country-specific electricity inventories to the new ecoinvent v3 database. Detailed instructions on how to import the project into SimaPro are given in Appendix: Instructions for importing and using the data in SimaPro.

4.1 Starting point: ecoinvent v3 country-specific datasets

In order to fully integrate the electricity scenarios in the ecoinvent v3 database the existing electricity datasets from the consequential system model are modified by means of a series of parameters or switches. The starting point for these adaptations are the market datasets for electricity production at high voltage (HVolt), such as 'Electricity, high voltage {DE}| market for | Conseq, U', which is the dataset for production of electricity at high voltage in Germany.

With this approach, when the electricity inventories are imported into SimaPro, they do not appear as additional datasets, but as modifications of the existing ecoinvent datasets for the affected countries. The only exceptions to this are:

- EU28
- US
- World

In these three cases new datasets were created, the reason being that ecoinvent currently does not have specific datasets for these regions that could be modified for our purposes.

4.2 Switches in SimaPro

The switches defined are, as already presented (see Scenario switches in SimaPro):

- e1: switches on the default ecoinvent v3 electricity scenario (with the exception of US, GLO, and EU28, where an average mix is switched on).
- e2: switches on the clca_future scenario.
- e3: switches on the clca_historical scenario.
- e4: switches on the clca_coal scenario.

For each flow in an inventory, the amount is calculated as:

e1*A+e2*B+e3*C+e4*D (eq.1)

Where A, B, C and D are the shares that this flow represents in each of the four scenarios. For example, in the production of high voltage electricity in Malaysia (Electricity, high voltage {MY}| market for | Conseq, U), the following line is written for the flow of electricty from hard coal:

e1*0.558+e2*0.605+e3*0.696+e4*1 (eq. 2)

Where A = 0.558, B = 0.605, C = 0.696 and D = 1. These are the shares of hard coal in the Malaysian mix according to the default ecoinvent , clca_future, clca_historical, and clca_coal, respectively. By choosing '1' for one the four parameters in the parameters section of SimaPro, we switch 'on' the corresponding term of the equation we are interested in, while keeping the other terms inactive.

4.3 Production of electricity at high, medium and low voltage

In ecoinvent v3, electricity producers supply electricity mostly at HVolt. However, there is also some supply at medium voltage (MVolt) and at low voltage (LVolt), especially for small and decentralized production, such as photovoltaics. An example is Germany, where there is some electricity input from gas turbines at MVolt, and some photovoltaic input at LVolt. When implementing our consequential inventories in ecoinvent v3, we have simplified this, and assumed that all producers supply electricity at HVolt only, and then the transformation losses are taken into account when converting to MVolt and LVolt. In order to do this, it was necessary to adapt also the market datasets for MVolt and/or LVolt, by adding the switches in eq. 1. For example, in the case of Germany we had to adapt both.

4.4 Matching production technologies

The translation of our consequential scenarios, based on this classification, into existing ecoinvent v3 datasets involved several choices, often related to the fact that our scenarios classify electricity production technologies at a less detailed level than ecoinvent v3.

Technology shares

In the present project, electricity production is classified according to the following technologies (see chapter 1):

- Coal
- Oil
- Gas
- Biomass
- Nuclear
- Hydro
- Wind
- Geothermal
- Solar
- Marine

We needed to define how to deal with multiple entries in the ecoinvent v3 dataset. As an example, the consequential scenarios have a single entry for wind power (as seen in the bullets above), whereas ecoinvent v3 discriminates between several types of capacities/plant types. Rather than choosing one type to represent all the wind power production in our consequential scenarios, we decided to keep all those present in the ecoinvent dataset, keeping the relative share that they have.

Table 2. Example of defining the share of different production technologies belonging to the same group, in the country mix for Germany and wind power production.

Electricity input	Amount (kWh per kWh country mix HVolt)[1]	Share
Electricity, high voltage {DE}| electricity production, wind, <1MW turbine, onshore | Conseq, U	0.0203	0.163
Electricity, high voltage {DE}| electricity production, wind, >3MW turbine, onshore | Conseq, U	0.0109	0.087
Electricity, high voltage {DE}| electricity production, wind, 1-3MW turbine, offshore | Conseq, U	0.0003	0.002
Electricity, high voltage {DE}| electricity production, wind, 1-3MW turbine, onshore | Conseq, U	0.0933	0.748
Total of group	**0.1247**	**1.00**

[1] As in 'Electricity, high voltage {DE}| market for | Conseq, U'.

Table 2 shows how this has been done for wind power production in Germany, where the HVolt default consequential mix in ecoinvent v3 includes 12.5% electricity from this source, obtained by different production plant types. From the contribution of each plant type a relative share is calculated, which we have used to split our consequential wind power production into these plant types. This is implemented in SimaPro by applying a modification in eq.2 as follows:

e1*A*share+e2*B*share+e3*C*share+e4*D*share (eq. 3)

Where 'share' is the share of this production type, calculated as shown in Table 2. Following the example of wind power in Germany, we can illustrate eq. 3 for the input of <1MW onshore production, as follows:

Share: as in table 1

e1*0.0203+e2*0.382*0.163+e3*0.328*0.163+e4*0*0.163 (eq. 4)

A: as in table 1

B: 38.2% of electricity from wind in clca_future scenario

D: 0% of electricity from wind in clca_coal scenario

C: 32.8% of electricity from wind in clca_historical scenario

The same calculations are carried out for the other wind power plants in Table 2. This split into different production capacities, types of plants, etc., has been necessary in many of the electricity production classifications used in the consequential mixes, including wind, coal, hydropower, and photovoltaics.

It must be highlighted that the ‘share’ parameter in eq. 3 has not been implemented in SimaPro as a parameter. Instead, for each each country we have calculated the specific values and entered them in the inventories.

Adding missing technologies

In some cases the ecoinvent v3 datasets for HVolt electricity production do not include a production technology that is needed either for the clca_future, clca_historical or clca_coal scenarios. An example of this is if the ecoinvent dataset does not include production from coal, which is needed for the clca_coal scenario. In these cases we need to add these entries to the dataset, and in this section we describe which datasets were chosen to fill these gaps:

- Photovoltaics: as previously mentioned, photovoltaic production is considered only at LVolt in ecoinvent 3. In order to add it to the HVolt production in our clca scenarios, we simply used the same datasets used in LVolt and added them in HVolt, considering the share of each plant type as described in the previous section (Technology shares). Having photovoltaics both in the HVolt and LVolt does not incur in double counting, provided that the switches are used correctly. Nevertheless, there is an inconsistency, since all the datasets for photovoltaic electricity are modelled as providing electricity in LVolt, i.e. in ecoinvent v3 there are no datasets for production of photovoltaics at HVolt that we could use in the HVolt country mixes. Therefore, the country mixes at HVolt include photovoltaic production at LVolt, since there was no other option at this stage.
- Oil: whenever electricity from oil was required, the datasets ‘Electricity, high voltage {country}| electricity production, oil | Conseq, U’ were used.
- Gas: whenever electricity from gas was required, the datasets ‘Electricity, high voltage {country}| electricity production, natural gas, at conventional power plant | Conseq, U’ was used.
- Biomass: ecoinvent v3 does not include consequential datasets for production of electricity from biomass. Thus, it was decided to produce specific inventories for this process, which are described in section 4.6.

Data for individual electricity production technologies when specific countries are missing

Not all electricity production technologies in ecoinvent v3 cover all the countries needed in our project. Whenever a country was missing in a certain technology, we opted for using another country as a surrogate. An example of this is photovoltaic electricity production in Brazil, which is not included in the database. In this particular case, we chose Germany as a surrogate. Surrogates are defined case by case in chapter 1, where the country-specific data are presented.

4.5 Transmission and distribution

Conversion of electricity to MVolt, LVolt, and distribution are modelled using ecoinvent v3. Transmission losses, emissions, etc. are not modified, however, some datasets were subject to the inclusion of switches, as explained in section 4.3.

4.6 Electricity from biomass

All electricity production technologies were modelled using existing ecoinvent v3 datasets, with the exception of biomass, for which a dataset is not available. For this reason this section presents a life cycle inventory of the activities involved in production of electricity from biomass (wood pellets) with a consequential LCI modelling approach. This is a global dataset, used in all country mixes where biomass is identified as an affected technology. Since the market for wood pellets is considered global, the activity is carried out applying global geographical system delimitation.

The inventory is carried out in four steps:

- Production of electricity (Table 3)
- Production of wood pellets (Table 4)
- Forestry activities (Table 5)

Electricity production (Table 3) considers a 41.6% efficiency in converting biomass energy into electricity (Prapaspongsa et al. 2010). The process 'Burning of wood pellets {RoW}' is based on the ecoinvent v3 dataset 'Heat, central or small-scale, other than natural gas {RoW}| heat production, wood pellet, at furnace 50kW | Conseq, U', where the default wood pellet production according to ecoinvent v3 has been replaced to include pellet production according to Table 4. The original reference product in that dataset was 1 MJ of useful heat delivered by the furnace, whereas in our modified dataset the reference product is changed to reflect the total heat produced by the combustion (1.19 MJ instead of 1 MJ).

Table 3. Inventory for production of electricity from wood pellets.

Flows	Wood pellets burned in power plant	Unit	LCI data
Outputs			
Electricity, high voltage	1	kWh	Reference flow
Inputs			
Burning of wood pellets {RoW}	8.72	MJ	Efficiency in electricity production: 41.3%, from Prapaspongsa et al. (2010). Combustion dataset based on ecoinvent v3 dataset 'Heat, central or small-scale, other than natural gas {RoW}| heat production, wood pellet, at furnace 50kW | Conseq, U' (see text).

Table 4 presents the inventory data for the production of wood pellets. The data are based on Prapaspongsa et al. (2010). Electricity production is split at 50% between the two marginal suppliers of biomass considered, namely Brazil and Chile. According to Reinhard et al. (2010) the marginal source of unspecified hardwood and softwood can be identified as eucalyptus wood from plantations in Brazil and pine wood from plantations in Chile, respectively.

The emissions associated with combustion of wood in the wood pellet production process were obtained from a modified version of the dataset 'Heat, central or small-scale, other than natural gas {RoW}| heat production, wood pellet, at furnace 50kW | Conseq, U', where only the combustion emissions and the disposal of ashes is kept, whereas all the other inputs are excluded. The original reference product in that dataset was 1 MJ of useful heat delivered by the furnace, whereas in our modified dataset the reference product is changed to reflect the total heat produced by the combustion (1.19 MJ instead of 1 MJ).

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

Flows	Wood pellets	Unit	LCI data
Outputs			
Wood pellets	1	kg DM	Reference flow
Inputs			
Wood, feedstock	1	kg DM	See **Table** 5
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 **Table** 5
Diesel incl. combustion	0.208	MJ	'Diesel, burned in building machine {GLO}| market for | Conseq, U'
Electricity {BR}	0.133	kWh	'Electricity, medium voltage {BR} | market for | Conseq, U'. 50% of total consumption of 0.266 kWh in the original source.
Electricity {CL}	0.133	kWh	'Electricity, medium voltage {CL} | market for | Conseq, U'. 50% of total consumption of 0.266 kWh in the original source.
Natural gas incl. combustion	3.17	MJ	'Heat, district or industrial, natural gas {RoW}| heat production, natural gas, at industrial furnace > 100 kW | Conseq, U'
Wood pellet plant	1.55E-11	p	'Wood pellet factory {GLO}| market for | Conseq, U
Emissions			
Emissions from burning wood	0.187	kg DM	Based on 'Heat, central or small-scale, other than natural gas {RoW}| heat production, wood pellet, at furnace 50kW | Conseq, U' (see text).

The forestry activities involved in production of wood are shown in Table 5. The data are based on Prapaspongsa et al. (2010). The inventory includes indirect land use change (iLUC) from Schmidt et al. (2015). The inventory flow included in the table for this activity is the net primary productivity (NPP_0), measured as kg of carbon per hectare per year. Specific NPP_0 values for land in Chile and Brazil are used, obtained from Haberl et al. (2007).

Table 5: 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
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	4,077	4,077	MJ	'Diesel, burned in building machine {GLO}| market for | Conseq, U'
N-Fertiliser, as N	10.2	10.2	kg	'Ammonium nitrate, as N {GLO}| market for | Conseq, U'
P-Fertiliser, as P_2O_5	17.1	17.1	kg	'Phosphate fertiliser, as P2O5 {GLO}| market for | Conseq, U'
K-Fertiliser, as K_2O	12.3	12.3	kg	'Potassium chloride, as K2O {GLO}| market for| Conseq, U'
Glyphosate	3.16	3.16	kg	'Glyphosate {GLO}| market for| Conseq, U'
Insecticide	0.143	0.143	kg	'Pesticide, unspecified {GLO}| market for| Conseq, U'
Limestone	143	143	kg	'Limestone, crushed, for mill {GLO}| market for| Conseq, U'
Lubricant oil + decomposition (C)	3.27	3.27	kg	'Lubricating oil {GLO}| market for| Conseq, U'
Land tenure, intensive forest land (NPP_0)	9,000	4,000	Kg C	Schmidt et al. (2015)
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

5 Definition of country and region mixes

In this section we describe the electricity production mixes for all the countries currently included in the project, including the data sources, assumptions, etc. Three mixes are presented for each country: consequential future (clca_future), consequential historical (clca_historical) and consequential coal (clca_coal).

5.1 Coverage overview

As a summary of the current coverage of the project, Table 6 provides the list of countries included so far as well as the years on which the mixes are based.

Table 6. Electricity LCI coverage overview.

Country/region	Acronym	Consequential historical period	Consequential future period
Belgium	BE	2000-2008	2008-2020
Brazil	??	2000-2008	2008-2020
Switzerland	??	2000-2010	2010-2020
China	CN	2000-2008	2008-2020
Czech Republic	CZ	2000-2008	2008-2020
Germany	DE	2000-2012	2012-2020
Denmark	DK	2000-2012	2012-2020
Spain	ES	2000-2012	2012-2020
Finland	FI	2000-2008	2008-2020
France	FR	2000-2008	2008-2020
United Kingdom	GB	2000-2012	2012-2020
Indonesia	ID	2000-2008	2008-2020
India	IN	2000-2008	2008-2020
Europe	EU28	2000-2008	2008-2020
Malaysia	MY	2000-2008	2008-2020
Mexico	MX	2000-2008	2008-2020
Poland	PL	2000-2010	2010-2020
Sweden	SE	2000-2012	2012-2020
United States	US	2000-2008	2008-2020
World	GLO	2000-2008	2008-2020

5.2 Belgium (BE)

Data on electricity production from different energy sources are presented in Table 7, which shows the generation in 2000 and 2008 and the predicted generation in 2020. Data for year 2000 and 2008 are from IEA (2010, p IV 165). The gross electricity production for 2020 is obtained by the predicted gross electricity consumption in 2020 (European Commission 2010) plus the exports and minus the imports of electricity as predidcted by IEA (2009). The electricity mix includes the production from renewable sources as declared in European Commission (2010) and the total remaining production from non-renewable sources is calculated as the total production minus the production from renewable sources. The ratios between non-renewable sources as predicted for 2020 in IEA (2009) are applied.

Table 7: Data for power generation in Belgium 2000, 2008 and 2020. Data from IEA (2010, p IV 165), IEA (2009) and European Commission (2010).

Source of electricity	Generation in 2000 TWh	Generation in 2008 TWh	Predicted generation in 2020 TWh
Coal	16	7	18
Oil	1	0	2
Gas	16	25	29
Biomass	1	4	11
Nuclear	48	46	32
Hydro	2	2	0
Wind	0	1	10
Geothermal	0	0	0
Solar	0	0	1
Marine	0	0	0
Total	**84**	**85**	**103**

Based on the information in Table 7, three electricity mixes are derived. In Table 8, the scenario 'Consequential future' is calculated from the predicted changes from 2008 to 2020. 'Consequential historical' is calculated in the same way, but by using the historical data from 2000 and 2008 in Table 7. 'Consequential coal' only includes coal.

Table 8: Data for the three consequential scenarios in Belgium.

Source of electricity	Consequential future		Consequential historical		Consequential coal
	Predicted change in generation 2008-2020, TWh	Applied electricity mix	Change in generation 2000-2008, TWh	Applied electricity mix	Applied electricity mix
Coal	11	0.318	-9*	0.000	1.000
Oil	1	0.042	0	0.000	--
Gas	4	0.122	9	0.694	--
Biomass	7	0.194	3	0.250	--
Nuclear	-14*	0.000	-3*	0.000	--
Hydro	-1*	0.000	0	0.008	--
Wind	10	0.289	1	0.048	--
Geothermal	0	0.001	0	0.000	--
Solar	1	0.033	0	0.000	--
Marine	0	0.000	0	0.000	--
Total	**19**	**1.000**	**1**	**1.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

The ecoinvent dataset for production of electricity at HVolt in Belgium does not include geothermal production. In addition, the ecoinvent database does not have dataset for this technology in Belgium. In order to incorporate this technology in the country mix, the dataset for geothermal electricity production in Germany was used as a surrogate (Electricity, high voltage {DE}| electricity production, geothermal | Conseq, U).

5.3 Brazil (BR)

Table 7 shows the electricity generation in 2000, 2008, and the predicted generation in 2020 in Brazil. Data are from IEA (2002, p 486-7) and the IEA (2010, p 694-5).

Table 9: Data for power generation in Brazil 2000, 2008 and 2020. Data from IEA (2002, p 486-7) and IEA (2010, p 694-5).

Source of electricity	Generation in 2000 TWh	Generation in 2008 TWh	Predicted generation in 2020 TWh
Coal	10	13	26
Oil	17	18	11
Gas	2	29	90
Biomass	9	20	29
Nuclear	6	14	24
Hydro	305	370	440
Wind	0	1	9
Geothermal	0	0	0
Solar	0	0	2
Marine	0	0	0
Total	**349**	**465**	**631**

The three electricity mixes are derived in Table 10. The scenario 'Consequential future' is calculated from the predicted changes from 2008 to 2020. 'Consequential historical' is calculated in the same way, but by using the historical data from 2000 and 2008. 'Consequential coal' only includes coal.

Table 10: Data for the three consequential and the attributional scenario in Brazil.

Source of electricity	Consequential future		Consequential historical		Consequential coal
	Predicted change in generation 2008-2020, TWh	Applied electricity mix	Change in generation 2000-2008, TWh	Applied electricity mix	Applied electricity mix
Coal	13	0.075	3	0.026	1.000
Oil	-7*	0.000	1	0.009	--
Gas	61	0.353	27	0.233	--
Biomass	9	0.052	11	0.095	--
Nuclear	10	0.058	8	0.069	--
Hydro	70	0.405	65	0.560	--
Wind	8	0.046	1	0.009	--
Geothermal	0	0.000	0	0.000	--
Solar	2	0.012	0	0.000	--
Marine	0	0.000	0	0.000	--
Total	**166**	**1.000**	**116**	**1.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

The ecoinvent datasets for production of electricity at HVolt in Brazil do not include photovoltaic production. In addition, the ecoinvent database does not include datasets for photovoltaic electricity production in this country that we can add. In order to incorporate this technology in the country mix, the same datasets used in Germany were used as a surrogate:

- Electricity, low voltage {DE}| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted | Conseq, U (50%)

- Electricity, low voltage {DE}| electricity production, photovoltaic, 3kWp slanted-roof installation, single-Si, panel, mounted | Conseq, U (40%)
- Electricity, low voltage {DE}| electricity production, photovoltaic, 570kWp open ground installation, multi-Si | Conseq, U (10%)

The same mix of these three technologies as applied in Germany was applied to Brazil. The percentages in brackets above show the percentages applied, which correspond to the 'share' component in eq. 3.

5.4 Switzerland (CH)

Data for production of electricity in Switzerland were obtained from the country's Energy strategy for 2050 (Swiss Federal Office of Energy 2013, pp. 88-89). This document reports electricity production by technology in the years 2000 and 2010, and predicts it for years 2020, 2035 and 2050. Table 11 shows the country mixes obtained from this source, for years 2000, 2010 and 2020.

Table 11: Data for power generation in Switzerland in 2000, 2010 and 2020. Data from the Swiss Federal Office of Energy (2013, pp. 88-89).

Source of electricity	Generation in 2000 TWh	Generation in 2010 TWh	Predicted generation in 2020 TWh
Coal	0	0	0
Oil	0.2	0.1	0.10
Gas	1.59	2.08	3.03
Biomass	0.8	1.26	2.31
Nuclear	24.73	25.13	21.68
Hydro	38.2	37.8	41.96
Wind	0	0.04	0.66
Geothermal	0	0	0.20
Solar	0	0.08	1.26
Marine	0	0	0
Total	**65.52**	**66.49**	**66.49**

The consequential historical mix was derived from the period 2000-2010, whereas the consequential future mix was derived from the period 2010-2020. The consequential coal scenario, on the other hand, only considers coal as an electricity source. The obtained electricity profiles can be seen in Table 12.

Table 12: Data for the three consequential scenarios in Switzerland.

Source of electricity	Consequential future		Consequential historical		Consequential coal
	Predicted change in generation 2010-2020, TWh	Applied electricity mix	Change in generation 2000-2010, TWh	Applied electricity mix	Applied electricity mix
Coal	0.00	0.000	0.00	0.000	1.000
Oil	0.00	0.000	-0.10	0.000	--
Gas	0.95	0.116	0.49	0.333	--
Biomass	1.05	0.129	0.46	0.313	--
Nuclear	-3.45	0.000	0.40	0.272	--
Hydro	4.16	0.510	-0.40	0.000	--
Wind	0.62	0.076	0.04	0.027	--

Geothermal	0.20	0.025	0.00	0.000	--
Solar	1.18	0.145	0.08	0.054	--
Marine	0.00	0.000	0.00	0.000	--
Total	**4.71**	**1.000**	**0.97**	**0.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

Several additions were needed in order to implement these inventories in the original ecoinvent 3 datasets for electricity production in Switzerland:

- In ecoinvent there is no dataset for electricity production from hard coal in Switzerland. In order to fill this gap, the dataset for production in Germany was used (Electricity, high voltage {DE}| electricity production, hard coal | Conseq)
- The original consequential dataset for electricity production in Switzerland does not include nuclear energy. In ecoinvent there are two types of nuclear reactors, namely boiling water and pressure water reactors. In order to implement nuclear energy in the consequential scenario, it was decided to use a technology mix as used in the attributional version of electricity production in Switzerland according to the ecoinvent database. This corresponds to 47% boiling water reactor and 53% pressure water reactor.
- In ecoinvent there is no dataset for electricity production from geothermal energy in Switzerland. In order to fill this gap the dataset for production in Germany was used (Electricity, high voltage {DE}| electricity production, geothermal | Conseq).
- In ecoinvent there is no dataset for electricity production from natural gas in a conventional power plant in Switzerland, which is the default option chosen for adapting our inventories to ecoinvent v3 (see section 4.4). In order to fill this gap the dataset for production in a 10 MW plant in Switzerland was used (Electricity, high voltage {DE}| electricity production, natural gas, 10MW | Conseq).

5.5 China (CN) 

Data for China on electricity production from different energy sources and the application of these data in the three consequential scenarios are presented in this section. Table 13 shows the generation in 2000 and 2008 and the predicted generation in 2020. Data are from IEA (2002, p 463-4) and the IEA (2010, p 670-3).

Table 13: Data for power generation in China 2000, 2008 and 2020. Data from IEA (2002, p 463-4) and IEA (2010, p 670-3).

Source of electricity	Generation in 2000 TWh	Generation in 2008 TWh	Predicted generation in 2020 TWh
Coal	1,081	2,759	4,595
Oil	46	24	26
Gas	19	43	332
Biomass	0	2	36
Nuclear	17	68	522
Hydro	222	585	1,094
Wind	1	13	319
Geothermal	0	0	3
Solar	0	0	15
Marine	0	0	0
Total	**1,386**	**3,494**	**6,942**

The three electricity mixes are derived in Table 14. The scenario ‘Consequential future’ is calculated from the predicted changes from 2008 to 2020. ‘Consequential historical’ is calculated in the same way, but by using the historical data from 2000 and 2008. ‘Consequential coal’ only includes coal.

Table 14: Data for the three consequential scenarios in China.

Source of electricity	Consequential future		Consequential historical		Consequential coal
	Predicted change in generation 2008-2020, TWh	Applied electricity mix	Change in generation 2000-2008, TWh	Applied electricity mix	Applied electricity mix
Coal	1,836	0.532	1,678	0.788	1.000
Oil	2	0.001	-22*	0.000	--
Gas	289	0.084	24	0.011	--
Biomass	34	0.010	2	0.001	--
Nuclear	454	0.132	51	0.024	--
Hydro	509	0.148	363	0.170	--
Wind	306	0.089	12	0.006	--
Geothermal	3	0.001	0	0.000	--
Solar	15	0.004	0	0.000	--
Marine	0	0.000	0	0.000	--
Total	**3,448**	**1.000**	**2,108**	**1.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

The ecoinvent dataset for production of electricity at HVolt in China does not include geothermal production. In addition, the ecoinvent database does not have dataset for this technology in Belgium. In order to incorporate this technology in the country mix, the dataset for geothermal electricity production in the RoW region was used as a surrogate (Electricity, high voltage {RoW}| electricity production, geothermal | Conseq, U).

5.6 Czech Republic (CZ) 

Data on electricity production from different energy sources and the application of these data in the three consequential scenarios for the Czech Republic is shown in Table 15. Electricity generation in 2000 and 2008 and the predicted generation in 2020, as well as data for 2000 and 2008 are from IEA (2010, p IV 201). The electricity generation for 2020 is obtained by the predicted gross eletricity consumption in 2020 (European Commission 2010) plus the exports and minus the imports of electricity as predicted by IEA (2010b). The electricity mix includes the production from renewable sources as declared in European Commission (2010) and the total remaining production from non-renewable sources is calculated as the total production minus the production from renewable sources. The ratios between non-renewable sources as predicted for 2020 in IEA (2010b) are applied.

Table 15: Data for power generation in Czech Republic 2000 and 2008 obtained from IEA (2010a, p IV 201); data 2020 from the European Commission (2010) and IEA (2010b, p 144 – Annex B).

Source of electricity	Generation in 2000 TWh	Generation in 2008 TWh	Predicted generation in 2020 TWh
Coal	53	50	37
Oil	0	0	1
Gas	3	3	9
Biomass	1	2	6
Nuclear	14	27	27
Hydro	2	2	2
Wind	0	0	1
Geothermal	0	0	0
Solar	0	0	2
Marine	0	0	0
Total	**73**	**84**	**86**

The three electricity mixes are derived in Table 16. The scenario 'Consequential future' is calculated from the predicted changes from 2008 to 2020. 'Consequential historical' is calculated in the same way, but by using the historical data from 2000 and 2008. 'Consequential coal' only includes coal.

Table 16: Data for the three consequential scenarios in the Czech Republic.

Source of electricity	Consequential future		Consequential historical		Consequential coal
	Predicted change in generation 2008-2020, TWh	Applied electricity mix	Change in generation 2000-2008, TWh	Applied electricity mix	Applied electricity mix
Coal	-13*	0.000	-4*	0.000	1.000
Oil	1	0.065	0	0.000	--
Gas	6	0.401	0	0.000	--
Biomass	5	0.304	1	0.057	--
Nuclear	0	0.031	13	0.922	--
Hydro	0	0.000	0	0.007	--
Wind	1	0.085	0	0.014	--
Geothermal	0	0.001	0	0.000	--
Solar	2	0.113	0	0.000	--
Marine	0	0.000	0	0.000	--
Total	**2**	**1.000**	**10**	**1.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

In ecoinvent v3 there is no dataset for electricity production from geothermal energy in the Czech Republic. In order to fill this gap the dataset for production in Germany was used (Electricity, high voltage {DE}| electricity production, geothermal | Conseq).

5.7 Germany (DE)

Data on electricity production from different energy sources and the application of these data in the three consequential scenarios for Germany are presented in this section. Table 17 shows the electricity generation in 2008 and 2011 and the predicted generation in 2020. Data for 2008 are from IEA (2011). Data for 2011 are from IEA (2013). The electricity generation for 2020 is equal to the predicted gross eletricity consumption in 2020 (IEA 2013). Furthermore, it has been assumed that nuclear plants are phased out in 2020 (Spiegel 2011). The ratios 2020 predictions from IEA (2013) are readjusted to account for the nuclear phasing-out assumption. The 2020 predictions are obtained from the total output multiplied with each corresponding readjusted output shares.

Table 17: Data for power generation in Germany 2008, 2011 and 2020. Data from IEA (2011), IEA (2013), Spiegel (2011).

Source of electricity	Generation in 2000 TWh	Generation in 2011 TWh	Predicted generation in 2020 TWh
Coal	304	272	216
Oil	5	7	0
Gas	53	84	104
Biomass	10	44	57
Nuclear	170	108	0
Hydro	26	17	21
Wind	9	49	108
Geothermal	0	0	1
Solar	0	22	34
Marine	0	0	0
Total	**577**	**603**	**540**

The three electricity mixes are derived in Table 18. **T**he scenario 'Consequential future' is calculated from the predicted changes from 2011 to 2020. 'Consequential historical' is calculated in the same way, but by using the historical data from 2008 and 2011. 'Consequential coal' only includes coal.

Table 18: Data for the three consequential scenarios in Germany.

Source of electricity	Consequential future		Consequential historical		Consequential coal
	Predicted change in generation 2011-2020, TWh	Applied electricity mix	Change in generation 2000-2011, TWh	Applied electricity mix	Applied electricity mix
Coal	-56	0.000	-33	0.000	1.000
Oil	-7	0.000	2	0.014	--
Gas	20	0.185	31	0.243	--
Biomass	13	0.118	34	0.264	--
Nuclear	-108	0.000	-62	0.000	--
Hydro	4	0.035	-9	0.000	--
Wind	59	0.545	39	0.307	--
Geothermal	1	0.011	0	0.000	--
Solar	12	0.107	22	0.173	--
Marine	0	0.000	0	0.000	--
Total	**-63**	**1.000**	**26**	**1.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

5.8 Denmark (DK)

Data on electricity production from different energy sources and the application of these data in the three consequential scenarios and the attributional scenario are presented in this section. Table 19 shows the electricity generation in 2000 and 2012 and the predicted generation in 2020. Data for year 2000 and 2012 are obtained from statistics by the Danish Energy Agency (2015). The electricity generation for 2020 is obtained also from projections made by the Danish Energy Agency (2015). An important remark about the data in Table 19 is that it excludes the electricity produced as a by-product from district heating production. This is justified by the fact that in district heating production the determining product is heat rather than electricity, and therefore electricity from this origin is considered constrained.

Table 19: Data for power generation in Denmark 2000, 2012 and 2020. Data rom the Danish Energy Agency (2015).

Source of electricity	Generation in 2000 PJ	Generation in 2012 PJ	Predicted generation in 2020 PJ
Coal	62	23	9
Oil	18	1	0
Gas	30	4	1
Waste	2	0	0
Straw	0	1	1
Wind	17	70	105
Wood	0	6	9
Other renewable*	1	0	6
Total	130	105	130

* Mostly photovoltaic energy and some biogas, added up in a single figure in the original source. Biogas is neglected.

Based on the information in Table 19**,** the three electricity mixes are derived. In Table 20 the scenario 'Consequential future' is calculated from the predicted changes from 2012 to 2020. 'Consequential historical' is calculated in the same way, but by using the historical data from 2000 and 2012. 'Consequential coal' only includes coal.

In Table 20 the category 'biomass' includes waste, straw and wood. Also, the category 'solar' is equal to the category 'other renewable' in Table 19.

Table 20: Data for the three consequential scenarios in Denmark.

Source of electricity	Consequential future		Consequential historical		Consequential coal
	Predicted change in generation 2012-2020, TWh	Applied electricity mix	Change in generation 2000-2012, TWh	Applied electricity mix	Applied electricity mix
Coal	-3.85*	0.000	-10.96*	0.000	1.000
Oil	-0.09*	0.000	-4.69*	0.000	--
Gas	-0.93*	0.000	-7.02*	0.000	--
Biomass	0.64	0.054	1.44	0.090	--
Nuclear	0.00	0.000	0.00	0.000	--
Hydro	0.00	0.000	0.00	0.000	--
Wind	9.65	0.813	14.63	0.910	--
Geothermal	0.00	0.000	0.00	0.000	--
Solar	1.59	0.134	-0.24*	0.000	--
Marine	0.00	0.000	0.00	0.000	--
Total	**6.99**	**1.000**	**-6.83**	**1.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

5.9 Spain (ES)

Data on electricity production from different energy sources and the application of these data in the three consequential scenarios and the attributional scenario are presented in this section. Table 21 shows the electricity generation in 2000, 2012, and the predicted generation in 2020. Data for year 2000 were obtained from the International Energy Agency's online statistics (IEA 2012). Generation for year 2012 was obtained from Red Eléctrica Española (2015) whereas generation for 2020 is obtained from data published by the Spanish Ministry of Industry (Minetur 2011, p. 48-49), which includes predictions from expansion of renewable energy sources according to the Spanish Renewable Energy Plan (IDAE 2011).

Table 21: Power generation in Spain 2000, 2012 and 2020. Data are obtained from IEA (2012) and Minetur (2013, p. 48-49).

Source of electricity	Generation in 2000 TWh	Generation in 2012 TWh	Predicted generation in 2020 TWh
Coal	80.9	57.7	31.6
Oil	22.6	6.6	8.6
Gas	20.2	77.2	133.3
Biomass	2.1	4.8	12.2
Nuclear	62.2	61.5	55.6
Hydro	31.8	19.5	41.5
Wind	4.7	48.5	73.4
Geothermal	0	0.0	0.3
Solar	0	11.6	26.7
Marine	0	0.0	0.2
Total	**224.5**	**287.3**	**383.5**

Based on the information in Table 21 the three electricity mixes are derived. In Table 22**,** the scenario 'Consequential future' is calculated from the predicted changes from 2008 to 2020. 'Consequential historical' is calculated in the same way, but by using the historical data from 2000 and 2008. 'Consequential coal' only includes coal. It can be seen that 0.2% of the predicted generation in 2020 is foreseen to originate in marine energy sources. However, at present there are no LCI data available for this energy source in ecoinvent, and for this reason, and due to the low contribution to the overall mix, it has been neglected.

Table 22: Data for the three consequential scenarios in Spain.

Source of electricity	Consequential future		Consequential historical		Consequential coal
	Predicted change in generation 2012-2020, TWh	**Applied electricity mix**	**Change in generation 2000-2012, TWh**	**Applied electricity mix**	**Applied electricity mix**
Coal	-26.1*	0.000	-23.2*	0.000	1.000
Oil	2.0	0.016	-16.0	0.000	--
Gas	56.1	0.438	57.0	0.495	--
Biomass	7.4	0.058	2.7	0.023	--
Nuclear	-5.9*	0.000	-0.7*	0.000	--
Hydro	22.1	0.172	-12.3*	0.000	--
Wind	24.9	0.195	43.8	0.380	--
Geothermal	0.3	0.002	0.0	0.000	--
Solar	15.0	0.117	11.6	0.101	--
Marine	0.2	0.002**	0.0	0.000	--
Total	**96.1**	**1.000**	**62.8**	**1.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

** Neglected.

Currently there is no dataset in ecoinvent v3 for generation of electricity from geothermal sources in Spain. In order to consider this energy source in the consequential future electricity mix, the dataset for geothermal energy in Portugal has been used as a surrogate: Electricity, high voltage {PT}| electricity production, geothermal | Conseq.

5.10 Finland (FI) 

Table 23 shows the electricity generation in Finland in 2000 and 2008 and the predicted generation in 2020. Data for 2000 and 2008 are from IEA (2010, p IV.237). The electricity generation for 2020 is obtained from IEA (2008). The electricity mix includes the production from renewable sources as declared in European Commission (2010) and the total remaining production from non-renewable sources is calculated as the total production minus the production from renewable sources. The ratios between non-renewable sources as predicted for 2020 in IEA (2008) are applied.

Table 23: Data for power generation in Finland 2000, 2008 and 2020. Data from IEA (2010, p IV.237), IEA (2008) and the European Commission (2010).

Source of electricity	Generation in 2000 TWh	Generation in 2008 TWh	Predicted generation in 2020 TWh
Coal	13	14	18
Oil	1	0	1
Gas	10	11	15
Biomass	9	11	13
Nuclear	23	23	32
Hydro	15	17	14
Wind	0	0	6
Geothermal	0	0	0
Solar	0	0	0
Marine	0	0	0
Total	**70**	**77**	**100**

Based on Table 23 the three electricity mixes are derived. In Table 24 the scenario 'Consequential future' is calculated from the predicted changes from 2008 to 2020. 'Consequential historical' is calculated in the same way, but by using the historical data from 2000 and 2008. 'Consequential coal' only includes coal.

Table 24: Data for the three consequential scenarios in Finland.

Source of electricity	Consequential future		Consequential historical		Consequential coal
	Predicted change in generation 2008-2020, TWh	Applied electricity mix	Change in generation 2000-2008, TWh	Applied electricity mix	Applied electricity mix
Coal	4	0.154	1	0.157	1.000
Oil	0	0.006	0	0.000	--
Gas	4	0.159	1	0.157	--
Biomass	2	0.091	2	0.243	--
Nuclear	9	0.363	1	0.071	--
Hydro	-3*	0.000	2	0.343	--
Wind	6	0.227	0	0.029	--
Geothermal	0	0.000	0	0.000	--
Solar	0	0.000	0	0.000	--
Marine	0	0.000	0	0.000	--
Total	**23**	**1.000**	**7**	**1.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

5.11 France (FR)

Table 25 shows the electricity generation in France in 2000 and 2008 and the predicted generation in 2020. Data for 2000 and 2008 are from IEA (2010a, p IV 255). The electricity generation for 2020 is obtained by the predicted gross eletricity consumption in 2020 (European Commission 2010) plus the exports and minus the imports of electricity as predicted by IEA (2010b). The electricity mix includes the production from renewable sources as declared in European Commission (2010) and the total remaining production from non-renewable sources is calculated as the total production minus the production from renewable sources. The ratios between non-renewable sources as predicted for 2020 in IEA (2010b) are applied.

Table 25: Data for power generation in France 2000, 2008 and 2020. Data from IEA (2010a, p IV 255) and European Commission (2010).

Source of electricity	Generation in 2000 TWh	Generation in 2008 TWh	Predicted generation in 2020 TWh
Coal	31	27	17
Oil	7	6	7
Gas	12	22	60
Biomass	4	6	17
Nuclear	415	440	413
Hydro	72	68	72
Wind	0	6	58
Geothermal	0	0	0
Solar	0	0	7
Marine	1	1	1
Total	**541**	**575**	**652**

Based on the information in Table 25**,** the three electricity mixes are derived. In Table 26 the scenario 'Consequential future' is calculated from the predicted changes from 2008 to 2020. 'Consequential historical' is calculated in the same way, but by using the historical data from 2000 and 2008. 'Consequential coal' only includes coal.

Table 26: Data for the three consequential scenarios in France.

Source of electricity	Consequential future		Consequential historical		Consequential coal
	Predicted change in generation 2008-2020, TWh	Applied electricity mix	Change in generation 2000-2008, TWh	Applied electricity mix	Applied electricity mix
Coal	-10*	0.000	-4*	0.000	1.000
Oil	1	0.007	-1*	0.000	--
Gas	38	0.335	10	0.244	--
Biomass	11	0.099	2	0.054	--
Nuclear	-26*	0.000	24	0.570	--
Hydro	3	0.030	-4*	0.000	--
Wind	52	0.459	6	0.131	--
Geothermal	0	0.004	0	0.000	--
Solar	7	0.061	0	0.000	--
Marine	1	0.006	0	0.000	--
Total	**78**	**1.000**	**34**	**1.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

The ecoinvent dataset for production of electricity at HVolt in France does not include geothermal production. In addition, the ecoinvent database does not have a dataset for this technology in France. In order to incorporate this technology in the country mix, the dataset for geothermal electricity production in

Germany was used as a surrogate (Electricity, high voltage {DE}| electricity production, geothermal | Conseq, U).

5.12 United Kingdom (GB)

Data on electricity production in GB are shown in Table 27. This table shows the electricity generation in 2000 and 2012 and the predicted generation in 2020. Data for year 2000 and 2012 are from IEA (2012). The electricity generation for 2020 is obtained by the predicted gross eletricity consumption in 2020 (European Commission 2010) plus the exports and minus the imports of electricity as predicted by IEA (2006). The electricity mix includes the production from renewable sources as declared in European Commission (2010) and the total remaining production from non-renewable sources is calculated as the total production minus the production from renewable sources. The ratios between non-renewable sources as predicted for 2020 in IEA (2006) are applied.

Table 27: Data for power generation in GB 2000, 2012 and 2020. Data from IEA (2012), IEA (2006) and European Commission (2010, p 12,105).

Source of electricity	Generation in 2000 TWh	Generation in 2012 TWh	Predicted generation in 2020 TWh
Coal	122.3	144.2	72.9
Oil	8.4	3.1	2.8
Gas	148.1	100.1	134.9
Biomass	4.5	12.9	26.0
Nuclear	78.3	70.4	26.2
Hydro	7.8	8.3	6.3
Wind	0.9	19.6	78.0
Geothermal	0.0	0.0	0.0
Solar	0.0	0.0	2.0
Marine	0.0	0.0	4.0
Total	**370.3**	**358.5**	**354.0**

Based on the information in Table 27**,** the three electricity mixes are derived. In Table 28 the scenario 'Consequential future' is calculated from the predicted changes from 2012 to 2020. 'Consequential historical' is calculated in the same way, but by using the historical data from 2000 and 2012. 'Consequential coal' only includes coal.

Table 28: Data for the three consequential scenarios in GB.

Source of electricity	Consequential future		Consequential historical		Consequential coal
	Predicted change in generation 2012-2020, TWh	Applied electricity mix	Change in generation 2000-2012, TWh	Applied electricity mix	Applied electricity mix
Coal	-71	0.000	22	0.443	1.000
Oil	0	0.000	-5	0.000	--
Gas	35	0.310	-48	0.000	--
Biomass	13	0.116	8	0.170	--
Nuclear	-44	0.000	-8	0.000	--
Hydro	-2	0.000	0	0.009	--
Wind	58	0.520	19	0.378	--
Geothermal	0	0.000	0	0.000	--
Solar	2	0.018	0	0.000	--
Marine	4	0.036	0	0.000	--
Total	**-4**	**1.000**	**-12**	**1.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

5.13 Indonesia (ID)

Table 29 shows the electricity generation in 2000, 2008, and the predicted generation in 2020. Data for years 2000 and 2008 were obtained from the International Energy Agency's (IEA) online statistics for Indonesia (IEA 2014; 2014b), whereas generation for 2020 is obtained from the Indonesian national plan on electricity supply (PT PLN 2013).

Table 29: Data for power generation in Indonesia in 2000, 2008 and 2020.

Source of electricity	Generation in 2000 GWh	Generation in 2008 GWh	Predicted generation in 2020 GWh
Coal	34,002	61,392	236,196
Oil	18,342	42,949	3,183
Gas	26,090	25,212	72,259
Biomass	6	47	63
Hydro	10,016	11,528	24,988
Geothermal	4,869	8,309	45,402
Solar	0	0	94
Total	93,325	149,437	382,185

Based on the information in Table 29**,** the three electricity mixes are derived. In Table 30 the scenario 'Consequential future' is calculated from the predicted changes from 2008 to 2020. 'Consequential historical' is calculated in the same way, but by using the historical data from 2000 and 2008. 'Consequential coal' only includes coal.

Biomass and solar energy are excluded from the country mixes. This exclusion is due to the fact that when looking at the overall share of electricity produced (either by marginal or constrained) sources, each of these two are responsible of less than 1% of the total share, and therefore are neglected in the supply mix.

Table 30: Data for the three consequential scenarios in Indonesia.

Source of electricity	Consequential future		Consequential historical		Consequential coal
	Predicted change in generation 2008-2020, GWh	Applied electricity mix	Change in generation 2000-2008, GWh	Applied electricity mix	Applied electricity mix
Coal	174,804	0.64	27,390	0.48	1.00
Oil	-39,766*	0.00	24,607	0.43	0.00
Gas	47,047	0.17	-878*	0.00	0.00
Biomass	16**	0.00	41**	0.00	0.00
Hydro	13,460	0.05	1,512	0.03	0.00
Geothermal	37,093	0.14	3,440	0.06	0.00
Solar	94**	0.00	0*	0.00	0.00
Total	**232,748**	**1.00**	**56,112**	**1.00**	**1.00**

* Denotes suppliers which are not expected to respond to a change in demand.

** Not included in the consequential scenario due to low magnitude.

5.14 India (IN)

Table 31 shows electricity generation in India during the years 2000, 2008 and the predicted generation in 2020. Data are from IEA (2002, p 298) and IEA (2010, Annex B, p 697).

Table 31: Data for power generation in India 2000, 2008 and 2020. Data from IEA (2002 p 298; 2010, Annex B, p 697).

Source of electricity	Generation in 2000 TWh	Generation in 2008 TWh	Predicted generation in 2020 TWh
Coal	420	569	1,039
Oil	5	34	36
Gas	25	82	203
Biomass	0.4	2	14
Nuclear	17	15	66
Hydro	74	114	226
Wind	0.6	14	57
Geothermal	0	0	0
Solar	0	0	11
Marine	0	0	0
Total	**542**	**830**	**1,652**

Based on the information in Table 31**,** the three electricity mixes are derived. In Table 32 the scenario 'Consequential future' is calculated from the predicted changes from 2008 to 2020. 'Consequential historical' is calculated in the same way, but by using the historical data from 2000 and 2008. 'Consequential coal' only includes coal.

Table 32: Data for the three consequential scenarios in India.

Source of electricity	Consequential future		Consequential historical		Consequential coal
	Change in generation 2008-2020, TWh	Applied electricity mix	Predicted change in generation 2000-2008, TWh	Applied electricity mix	Applied electricity mix
Coal	470	0.572	149	0.514	1.000
Oil	2	0.002	29	0.100	--
Gas	121	0.147	57	0.197	--
Biomass	12	0.015	2	0.006	--
Nuclear	51	0.062	-2*	0.000	--
Hydro	112	0.136	40	0.138	--
Wind	43	0.052	13	0.046	--
Geothermal	0	0.000	0	0.000	--
Solar	11	0.013	0	0.000	--
Marine	0	0.000	0	0.000	--
Total	**822**	**1.000**	**288**	**1.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

5.15 Europe (EU28)

For Europe we do not only provide consequential electricity mixes, but also an average electricity mix. The reason is that currently ecoinvent does not have an electricity mix as such for Europe. Therefore, the ‘e1’ switch cannot be used in the same way as for other countries or regions where ecoinvent provides an electricity mix. In this project, the ‘e1’ switch provides an average electricity mix according to 2008.

Table 33 shows the generation of electricity in Europe during the years 2000, 2008, and the predicted generation in 2020. Data for 2000 and 2008 are from IEA (2010a, p IV.59) and data for 2020 are from IEA (2010c, p 636-8). Data from IEA (2010, 2010c) are based on the European countries being part of OECD and include the following countries: Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, and the United Kingdom. The electricity mixes for these countries are assumed to be representative for European electricity mix.

Table 33: Data for power generation in Europe 2000, 2008 and 2020. Data from IEA (2010, p IV.59) and IEA (2010c, p 636-8).

Source of electricity	Generation in 2000 TWh	Generation in 2008 TWh	Predicted generation in 2020 TWh
Coal	954	934	710
Oil	179	104	44
Gas	512	869	942
Biomass	49	113	183
Nuclear	935	922	909
Hydro	571	554	593
Wind	22	120	455
Geothermal	6	10	16
Solar	0	8	61
Marine	1	1	2
Total	**3,229**	**3,634**	**3,915**

Based on the information in Table 33, four electricity mixes are derived. In Table 34 the scenario 'Consequential future' is calculated from the predicted changes from 2008 to 2020. 'Consequential historical' is calculated in the same way, but by using the historical data from 2000 and 2008. 'Consequential coal' only includes coal, and the scenario 'Average 2008' is calculated directly from generation in 2008.

Table 34: Data for the three consequential scenarios in the EU28.

Source of electricity	Consequential future		Consequential historical		Consequential coal	Average 2008
	Predicted change in generation 2008-2020, TWh	Applied electricity mix	Change in generation 2000-2008, TWh	Applied electricity mix	Applied electricity mix	Applied electricity mix
Coal	-224*	0.000	-20*	0.000	1.000	0.257
Oil	-60*	0.000	-75*	0.000	--	0.029
Gas	73	0.127	357	0.674	--	0.239
Biomass	70	0.121	64	0.121	--	0.031
Nuclear	-13*	0.000	-13*	0.000	--	0.254
Hydro	39	0.067	-17*	0.000	--	0.153
Wind	335	0.580	98	0.185	--	0.033
Geothermal	6	0.011	4	0.007	--	0.003
Solar	54	0.093	7	0.014	--	0.002
Marine	2	0.003	0	0.000	--	0.000
Total	**281**	**1.000**	**405**	**1.000**	**1.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

The ecoinvent database currently does not have specific datasets for production of electricity in Europe as a whole. Instead, this is modelled in ecoivent as the sum of the individual European countries' datasets, weighted according to their contribution to the overall European electricity production. This arrangement is not suited for adaptation to our electricity inventories. For this reason we decided to create specific datasets for electricity in the EU28, using Germany as the starting dataset for electricity production. Overall, five datasets were created:

- Electricity, high voltage {EU28}| market for | CLCA
- Electricity, medium voltage {EU28}| electricity voltage transformation from high to medium voltage | CLCA
- Electricity, medium voltage {EU28}| market for | CLCA
- Electricity, low voltage {EU28}| electricity voltage transformation from medium to low voltage | CLCA
- Electricity, low voltage {EU28}| market for | CLCA

In the original DE datasets the name was changed to EU28, as seen above. Also, in the original datasets all the inputs refer to Germany as a region, and the share for technologies like photovoltaics and wind energy (as defined in Technology shares) refer to Germany too. These aspects have been kept in the new datasets above, where only the figures for electricity produced from each source have been changed, to reflect the EU28 data in Table 34, and thus replacing the original DE figures.

5.16 Mexico (MX)

Table 35 shows the electricity generation in Mexico during 2000 and 2008, and the predicted generation in 2020. Data for 2000 and 2008 are from IEA (2010, p IV.425). For 2020 a mixed procedure has been applied. In SENER (2010, p 103; 147; 149; 153; 158) the future plans of expanding the electricity capacity by 2020 are declared. This capacity has been multiplied by the average productivities of plants by energy source in 2008 (EIA, 2010, p IV.425; IV.435 - IV.436) and in this way the predicted electricity generation for the 2020 has been determined.

Table 35: Data for power generation in Mexico 2000, 2008 and 2020. Data from IEA (2010, p IV.425; IV.435 - IV.436) and SENER (2010, p 103; 147; 149; 153; 158).

Source of electricity	Generation in 2000 TWh	Generation in 2008 TWh	Predicted generation in 2020 TWh
Coal	19	21	24
Oil	90	49	33
Gas	40	131	213
Biomass	0	1	1
Nuclear	8	10	11
Hydro	33	39	44
Wind	0	0	19
Geothermal	6	7	8
Solar	0	0	0
Marine	0	0	0
Total	**196**	**259**	**352**

Based on the information in Table 35, the three electricity mixes are derived. In Table 38 the scenario 'Consequential future' is calculated from the predicted changes from 2008 to 2020. 'Consequential historical' is calculated in the same way, but by using the historical data from 2000 and 2008. 'Consequential coal' only includes coal.

Table 36: Data for the three consequential scenarios in Mexico.

Source of electricity	Consequential future		Consequential historical		Consequential coal
	Predicted change in generation 2008-2020, TWh	Applied electricity mix	Change in generation 2000-2008, TWh	Applied electricity mix	Applied electricity mix
Coal	2	0.020	2	0.022	1.000
Oil	-16*	0.000	-41*	0.000	--
Gas	81	0.744	91	0.885	--
Biomass	0	0.000	0	0.004	--
Nuclear	1	0.013	2	0.015	--
Hydro	5	0.044	6	0.059	--
Wind	19	0.172	0	0.003	--
Geothermal	1	0.005	1	0.012	--
Solar	0	0.002	0	0.000	--
Marine	0	0.000	0	0.000	--
Total	**93**	**1.000**	**63**	**1.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

5.17 Malaysia (MY)

Table 37 shows the electricity generation in Malaysia in 2000 and 2008, and the predicted generation in 2020. Data for 2000 and 2008 are from IEA (2002b, p I.34, I.41 and I.45) and IEA (2010d, p III.6, III.10 and III.14). The forecasted electricty production mix for the year 2020 is based on IEA (2009b, p 610).

Table 37: Data for power generation in Malaysia 2000, 2008 and 2020. Data from IEA (2002b, p I.34, I.41 and I.45), IEA (2010d, p III.6, III.10 and III.14) and IEA (2009b, p 610)

Source of electricity	Generation in 2000 TWh	Generation in 2008 TWh	Predicted generation in 2020 TWh
Coal	2	30	60
Oil	6	2	1
Gas	54	66	83
Biomass	0	0	0
Nuclear	0	0	0
Hydro	7	7	10
Wind	0	0	0
Geothermal	0	0	0
Solar	0	0	0
Marine	0	0	0
Total	**69**	**106**	**154**

Based on the information in Table 37**,** the three electricity mixes are derived. In Table 38 the scenario 'Consequential future' is calculated from the predicted changes from 2008 to 2020. 'Consequential historical' is calculated in the same way, but by using the historical data from 2000 and 2008. 'Consequential coal' only includes coal.

Table 38: Data for the three consequential scenarios in Malaysia.

Source of electricity	Consequential future		Consequential historical		Consequential coal
	Predicted change in generation 2008-2020, TWh	Applied electricity mix	Change in generation 2000-2008, TWh	Applied electricity mix	Applied electricity mix
Coal	30	0.605	28	0.696	1.000
Oil	-1*	0.000	-4*	0.000	--
Gas	17	0.348	12	0.292	--
Biomass	0	0.000	0	0.000	--
Nuclear	0	0.000	0	0.000	--
Hydro	2	0.046	1	0.012	--
Wind	0	0.000	0	0.000	--
Geothermal	0	0.000	0	0.000	--
Solar	0	0.000	0	0.000	--
Marine	0	0.000	0	0.000	--
Total	**48**	**1.000**	**37**	**1.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

5.18 Poland (PL)

Electricity generation in Poland in the years 2000 and 2010 was obtained from the International Energy Agency's online statistics (IEA 2012). A complete prediction of electricity generation in 2020 was not available. This was estimated based on the Polish national Renewable Energy Action Plan (Polish Ministry of Economy 2010). This plan only reports the expected increase in electricity production from renewable energy sources, whereas conventional energy sources are not reported. In order to produce a complete electricity mix for the country in 2020, the renewable energy figures were obtained from the country Plan, and data for coal, oil, and gas were estimated as follows:

- The total electricity produced by the sum of these sources was estimated as the total amount of electricity produced in the country in 2010 minus the expected production from renewables in 2020. This is 157.7 TWh – 33.0 TWh = 124.7 TWh.
- These 124.7 TWh were allocated to coal, oil, and gas in 2020, based on their relative contributions in 2010.

This estimate is based on the assumption that the total electricity generation in Poland in 2020 remains unchanged with respect to 2010, which is obviously a simplification. The resulting electricity generation is presented in Table 39.

Table 39: Data for power generation in Poland in 2000, 2010 and 2020. Data from IEA (2012) and Polish Ministry of Economy (2010).

Source of electricity	Generation in 2000 TWh	Generation in 2010 TWh	Predicted generation in 2020 TWh
Coal	137.7	138.3	118.11
Oil	1.9	2.9	2.48
Gas	0.9	4.8	4.10
Biomass	0.6	6.5	14.22
Nuclear	0	0	0
Hydro	4.1	3.5	2.9
Wind	0	1.7	15.21
Geothermal	0	0	0.18
Solar	0	0	0.5
Marine	0	0	0
Total	**145.2**	**157.7**	**157.70**

Based on data in Table 39, the three consequential electricity mixes are derived in Table 40. As shown, the consequential future scenario only considers renewables because we assume that fossil fuels decrease their share in the country's electricity generation. In this way, they are not considered as affected by a change in demand for electricity in the future scenario.

Table 40: Data for the three consequential scenarios in Poland.

Source of electricity	Consequential future		Consequential historical		Consequential coal
	Predicted change in generation 2010-2020, TWh	Applied electricity mix	Change in generation 2000-2010, TWh	Applied electricity mix	Applied electricity mix
Coal	-20.19*	0.000	0.6	0.046	1.000
Oil	-0.42*	0.000	1.0	0.076	--
Gas	-0.70*	0.000	3.9	0.298	--
Biomass	7.72	0.352	5.9	0.450	--
Nuclear	0.00	0.000	0.0	0.000	--
Hydro	-0.60*	0.000	-0.6*	0.000	--
Wind	13.51	0.617	1.7	0.130	--
Geothermal	0.18	0.008	0.0	0.000	--
Solar	0.50	0.023	0.0	0.000	--
Marine	0.00	0.000	0.0	0.000	--
Total	**0.00**	**1.000**	**12.5**	**1.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

Ecoinvent does not currently have datasets for Poland concerning electricity production from geothermal and photovoltaic energy sources. In order to implement our inventories including these technologies, the corresponding datasets for Germany were used as surrogates. For geothermal energy: Electricity, high voltage {DE}| electricity production, geothermal | Conseq. For photovoltaic energy, Germany has a mix of several capacities and configurations. The following datasets were used:

- Electricity, low voltage {DE}| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted | Conseq, U (50%)
- Electricity, low voltage {DE}| electricity production, photovoltaic, 3kWp slanted-roof installation, single-Si, panel, mounted | Conseq, U (40%)
- Electricity, low voltage {DE}| electricity production, photovoltaic, 570kWp open ground installation, multi-Si | Conseq, U (10%)

The same mix of these three technologies as applied in Germany was applied to Poland. The percentages in brackets above show the percentages applied, which correspond to the 'share' component in eq. 3.

5.19 Sweden (SE) 

Table 41 shows the electricity generation in Sweden in 2000 and 2012 and the predicted generation in 2020. Data for year 2000 and 2012 are from IEA (2012). The electricity generation for 2020 is obtained by the predicted gross eletricity consumption in 2020 (European Commission 2010) plus the exports and minus the imports of electricity as predicted by IEA (2006). The electricity mix includes the production from renewable sources as declared in European Commission (2010) and the total remaining production from non-renewable sources is calculated as the total production minus the production from renewable sources. The ratios between non-renewable sources as predicted for 2020 in IEA (2006) are applied.

Table 41: Data for power generation in Sweden 2000, 2012 and 2020. Data from IEA (2012), IEA (2006) and European Commission (2010, p 12,105).

Source of electricity	Generation in 2000 TWh	Generation in 2012 TWh	Predicted generation in 2020 TWh
Coal	2.5	1.3	1.3
Oil	1.5	0.6	0.7
Gas	0.5	0.9	0.9
Biomass	4.3	13.5	16.7
Nuclear	57.3	64.0	66.4
Hydro	78.6	79.1	68.0
Wind	0.5	7.2	12.5
Geothermal	0.0	0.0	0.0
Solar	0.0	0.0	0.0
Marine	0.0	0.0	0.0
Total	**145.3**	**166.6**	**166.6**

Based on the information in Table 41**,** the three electricity mixes are derived. In Table 42 the scenario 'Consequential future' is calculated from the predicted changes from 2012 to 2020. 'Consequential historical' is calculated in the same way, but by using the historical data from 2000 and 2012. 'Consequential coal' only includes coal.

Table 42: Data for the three consequential scenarios in Sweden.

Source of electricity	Consequential future		Consequential historical		Consequential coal
	Predicted change in generation 2012-2020, TWh	Applied electricity mix	Change in generation 2000-2012, TWh	Applied electricity mix	Applied electricity mix
Coal	0.05	0.004	-1.25*	0.000	1.000
Oil	0.02	0.002	-0.89*	0.000	--
Gas	0.03	0.003	0.43	0.018	--
Biomass	3.24	0.293	9.11	0.389	--
Nuclear	2.38	0.215	6.72	0.287	--
Hydro	-11.06	0.000	0.44	0.019	--
Wind	5.34	0.482	6.71	0.286	--
Geothermal	0.00	0.000	0.00	0.000	--
Solar	0.00	0.000	0.02	0.001	--
Marine	0.00	0.000	0.00	0.000	--
Total	**0.00**	**1.000**	**21.30**	**1.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

5.20 United States (US)

For the US we do not only provide consequential electricity mixes, but also an average electricity mix. The reason for this is that currently ecoinvent does not have an electricity mix as such for the US. Therefore, the 'e1' switch cannot be used in the same way as for other countries or regions where ecoinvent provides an electricity mix. In This project, the 'e1' switch provides an average electricity mix according to 2008.

Table 43 shows the generation of electricity in the US in 2000 and 2008 and the predicted generation in 2020. Data are from IEA (2010, p IV.637) and IEA (2010c, p 632-3).

Table 43: Data for power generation in the US in 2000, 2008 and 2020. Data from IEA (2010a, p IV.637) and IEA (2010b, p 632-3).

Source of electricity	Generation in 2000 TWh	Generation in 2008 TWh	Predicted generation in 2020 TWh
Coal	2,130	2,133	2,130
Oil	119	58	20
Gas	634	911	935
Biomass	72	72	138
Nuclear	797	838	895
Hydro	280	282	289
Wind	6	56	247
Geothermal	15	17	34
Solar	1	3	29
Marine	0	0	0
Total	**4,052**	**4,368**	**4,717**

Based on the information in Table 43**,** four electricity mixes are derived. In Table 44 the scenario 'Consequential future' is calculated from the predicted changes from 2008 to 2020. 'Consequential historical' is calculated in the same way, but by using the historical data from 2000 and 2008. 'Consequential coal' only includes coal and the scenario 'Average 2008' is calculated directly from generation in 2008.

Table 44: Data for the three consequential scenarios in the US.

Source of electricity	Consequential future		Consequential historical		Consequential coal	Average 2008
	Predicted change in generation 2008-2020, TWh	Applied electricity mix	Change in generation 2000-2008, TWh	Applied electricity mix	Applied electricity mix	Applied electricity mix
Coal	-3*	0.000	3	0.008	1.000	0.488
Oil	-38*	0.000	-61*	0.000	--	0.013
Gas	24	0.063	276	0.733	--	0.208
Biomass	66	0.169	1	0.002	--	0.017
Nuclear	57	0.147	41	0.108	--	0.192
Hydro	7	0.018	2	0.005	--	0.065
Wind	191	0.492	50	0.133	--	0.013
Geothermal	17	0.044	2	0.006	--	0.004
Solar	27	0.068	2	0.005	--	0.001
Marine	0	0.000	0	0.000	--	0.000
Total	**349**	**1.000**	**316**	**1.000**	**1.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

The ecoinvent database currently does not have specific datasets for production of electricity in the US as a whole. Instead, this is modelled in ecoinvent as the sum of the individual regional grid systems' datasets, weighted accordingly to their contribution to the overall US electricity production. This arrangement is not suited for adaptation to our electricity inventories. For this reason, we decided to create specific datasets for electricity in the US. We did this by using the Midwest Reliability Organization (MRO) as the starting dataset for electricity production. Overall, five datasets were created:

- Electricity, high voltage {US}| market for | CLCA
- Electricity, medium voltage {US}| electricity voltage transformation from high to medium voltage | CLCA
- Electricity, medium voltage {US}| market for | CLCA
- Electricity, low voltage {US}| electricity voltage transformation from medium to low voltage | CLCA
- Electricity, low voltage {US}| market for | CLCA

In the original MRO datasets the name was changed to US, as seen above. Also, in the original datasets all the inputs refer to MRO as a region, and the share for technologies like nuclear or hydropower (as defined in Technology shares) refer to MRO too. These aspects have been kept in the new datasets above, where only the figures for electricity produced from each source have been changed to reflect the EU28 data in Table 34, and thus replacing the original DE figures.

In addition, the MRO datasets for electricity production in ecoinvent v3 do not include photovoltaic electricity production, which is needed for the US electricity mix we needed to build. For this reason we used as surrogates the datasets used for photovoltaics in the Western Electricity coordinating Council (WECC). An inspection of the modelling of photovoltaics in the remaining US grid regions revealed that the share of different photovoltaic systems (power capacity, configuration, type of solar panel, etc.) is constant across US grid regions in ecoinvent v3, whereby our choice of WECC can be considered well aligned with the ecoinvent database.

5.21 World (GLO)

For the world electricity mix we do not only provide consequential electricity mixes, but also an average electricity mix. The reason for this is that currently ecoinvent does not have an electricity mix as such for the world. Therefore, the 'e1' switch cannot be used in the same way as for other countries or regions where ecoinvent provides an electricity mix. In This project, the 'e1' switch provides an average electricity mix according to 2008.

Table 45 shows the generation of electricity globally in the years 2000 and 2008 and the predicted generation in 2020. Data for 2000 are from IEA (2002, p 410-413) and data for 2008 and 2020 are from IEA (2010c, p. 620-621).

Table 45: Data for Global power generation in 2000, 2008 and 2020. Data from IEA (2002, p 410-413) and IEA (2010c, p 620-621).

Source of electricity	Generation in 2000 TWh	Generation in 2008 TWh	Predicted generation in 2020 TWh
Coal	5,989	8,273	10,630
Oil	1,241	1,104	689
Gas	2,676	4,303	5,881
Biomass	167	267	547
Nuclear	2,586	2,731	3,712
Hydro	2,650	3,208	4,367

Wind	31	219	1,229
Geothermal	49	65	131
Solar	2	13	186
Marine	0	1	2
Total	**15,391**	**20,184**	**27,374**

Based on the information in Table 45, four electricity mixes are derived. In Table 46, the scenario ‘Consequential future’ is calculated from the predicted changes from 2008 to 2020. ‘Consequential historical’ is calculated in the same way, but by using the historical data from 2000 and 2008. ‘Consequential coal’ only includes coal, and the scenario ‘Average 2008’ is calculated directly from generation in 2008.

Table 46: Data for the three consequential scenarios in the World.

Source of electricity	Consequential future		Consequential historical		Consequential coal	Average 2008
	Change in generation 2008-2020, TWh	Applied electricity mix	Change in generation 2000-2008, TWh	Applied electricity mix	Applied electricity mix	Applied electricity mix
Coal	2,357	0.310	2,284	0.463	1.000	0.410
Oil	-415*	0.000	-137*	0.000	--	0.055
Gas	1,578	0.207	1,627	0.330	--	0.213
Biomass	280	0.037	100	0.020	--	0.013
Nuclear	981	0.129	145	0.029	--	0.135
Hydro	1,159	0.152	558	0.113	--	0.159
Wind	1,010	0.133	188	0.038	--	0.011
Geothermal	66	0.009	16	0.003	--	0.003
Solar	173	0.023	11	0.002	--	0.001
Marine	1	0.000	1	0.000	--	0.000
Total	**7,190**	**1.000**	**4,793**	**1.000**	**1.000**	**1.000**

* Denotes suppliers which are not expected to respond to a change in demand.

The ecoinvent database does not have specific datasets for production of electricity globally. For this reason we created specific datasets for global electricity. We did this by using the RoW dataset as the starting dataset for electricity production. Overall, five datasets were created:

- Electricity, high voltage {GLO}| market for | CLCA
- Electricity, medium voltage {GLO}| electricity voltage transformation from high to medium voltage | CLCA
- Electricity, medium voltage {GLO}| market for | CLCA
- Electricity, low voltage {GLO}| electricity voltage transformation from medium to low voltage | CLCA
- Electricity, low voltage {GLO}| market for | CLCA

In the original RoW datasets the name was changed to GLO, as seen above. Also, in the original datasets all the inputs refer to RoW as a region, and the share for technologies like nuclear or hydropower (as defined in Technology shares) refer to RoW too. These aspects have been kept in the new datasets above, where only the figures for electricity produced from each source have been changed, to reflect the EU28 data in Table 34, and thus replacing the original RoW figures.

6 Summary of results: GHG emissions

In this section we show the impact assessment results for all the countries/regions included in the project, according to the following modelling options:

- Consequential future mix
- Consequential historical mix
- Consequential coal mix
- Original ecoinvent consequential mix (except for US, GLO and EU28, where an average mix is used)

The results are shown in Table 47, per kWh at medium voltage, for the impact category climate change, using the global warming potentials (GWP) from the third assessment report of the IPCC (2013).

Table 47: GHG emissions (kg CO2-eq./kWh at medium voltage) for all countries and modelling scenarios, excluding iLUC.

Country/region	Consequential ecoinvent (e1 switch)	Consequential future (e2 switch)	Consequential historical (e3 switch)	Consequential coal (e4 switch)
Belgium	0.14	0.53	0.45	1.17
Brazil	0.24	0.44	0.34	1.43
Switzerland	0.01	0.14	0.35	1.20
China	1.15	0.85	1.16	1.46
Czech Republic	0.78	0.56	0.03	1.27
Germany	0.99	0.17	0.26	1.23
Denmark	0.74	0.05	0.05	1.04
Spain	0.36	0.31	0.32	1.20
Finland	0.19	0.31	0.35	1.03
France	0.07	0.23	0.16	1.19
United Kingdom	0.85	0.20	0.62	1.29
Indonesia	1.03	0.97	1.17	1.37
India	1.50	1.20	1.25	1.91
Malaysia	0.94	1.01	1.11	1.42
Mexico	0.40	0.37	0.44	1.37
Poland	1.18	0.11	0.50	1.22
Sweden	0.02	0.10	0.13	1.05
Europe	0.55*	0.14	0.44	1.23
World	0.75*	0.58	0.86	1.22
United States	0.98*	0.12	0.70	1.54

* Average electricity mix 2008.

7 Conclusions

The present project provides an approach to derive consequential electricity mixes for countries and regions, using ecoinvent v3 as LCI data in the background. Up to date, such an approach was not available, leading to a risk of misleading decision support. Although, ecoinvent in its version 3 addresses consequential modelling, the approach taken for electricity mixes is currently insufficient and leads to unrealistic results. Our approach is causal-based, uses easily accessible data from national and international statistics, and is easy to update once new or better statistical data are available.

The main limitations are related to the difficulties in identifying electricity co-produced with heat, which is considered constrained and should therefore be excluded from the mixes. Also, there is a higher uncertainty in the consequential future mix rather than on the consequential historical mix, given that the former is based on future projections, which tend to be optimistic. On the other hand, the consequential historical mix is more precise, as it is entirely based on statistics, but fails to take into account the future impacts of new technologies and policies. A combination of these two modelling scenarios is recommended for use in LCA studies, the clca future scenario as a default and the clca historical in sensitivity analyses.

8 Q&A

8.1 Why doesn't the marginal supply include shrinking technologies in a stable/expanding electricity market?

Generally, marginal suppliers are defined as the ones being installed as a consequence of a change in demand – in increasing and stable markets (or when decrease is slower than replacement rate of capacity). (Weidema et al. 2009)

In the current project, the identification of the marginal suppliers of electricity is based on the assumption that the suppliers, which are predicted to increase their installed capacity, are the marginal ones, except when they are otherwise constrained, e.g. by a dependence on a waste or by-product as an input or if the increase is fixed by legislation or other factors not related to changes in demand. Technologies with no predicted increase or declining trends are regarded as not being part of the marginal. For furth details, see section 3.3.

To take a specific example: The suppliers in Denmark which are predicted to increase capacity are wind and biomass while one which is predicted to decrease is coal. This means that wind and biomass are marginal, whereas coal is not part of the marginal.

The above assumption could be challenged by arguing that a change in demand could also be met by a delay in the phase out of coal. This way of "regulating" the supply can indeed be a real way to regulate. However, compared to the general and overall trend of the installation of new capacity, it is very limited how much the phase out of old technologies can be delayed. The timing of the phase out of old technologies can provide a little flexibility and thereby be a small part of the marginal – but this can never be a significant part of the marginal.

Situations where the timing of phase out of old technologies serves some flexibility can be:

- When the is a significant amount of overcapacity of the old technology
- In very short periods of time, to solve short-term (quarters of years to entire years) need for capacity.

But still, it will never dominate the marginal.

References

Bauer C (2013) Electricity markets in different system models of the ecoinvent v3 database. Ecoinvent v3 talk page info: electricity markets. www.ecoinvent.ch

Danish Energy Agency (2015), Basisfremskrivninger. http://www.ens.dk/info/tal-kort/fremskrivninger-analyser-modeller/fremskrivninger (accessed 3/02/2015).

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

European Commission (2010), National Renewable Energy Action Plans for Belgium, prepared by the Federal-Regional Energy Consultation Group CONCERE-ENOVER, Belgium. Website: http://ec.europa.eu/energy/renewables/transparency_platform/action_plan_en.htm (Accessed: August 2011)

Haberl H., Erb, K.H., Krausmann, F., Gaube, V., Bondeau, A., Plutzar, C., Gingrich, S., Lucht, W., Fischer-Kowalski, M., (2007). Quantifying and mapping the global human appropriation of net primary production in Earth's terrestrial ecosystem. Proceedings of the National Academy of Sciences of the USA. 104: 12942-12947. http://www.uni-klu.ac.at/socec/inhalt/1191.htm (Accessed April 2013).

IDAE (2011): Plan de Energías Renovables 2011-2020. http://www.idae.es/index.php/id.670/relmenu.303/mod.pags/mem.detalle (Accessed 29/11/2013).

IEA (2014a): Indonesia: Electricity and Heat for 2000. http://www.iea.org/statistics/statisticssearch/report/?country=INDONESIA&product=electricityandheat&year=2000 (accessed 26/02/2014).

IEA (2014b): Indonesia: Electricity and Heat for 2008. http://www.iea.org/statistics/statisticssearch/report/?country=INDONESIA&product=electricityandheat&year=2008 (accessed 26/02/2014).

IEA (2013), Energy Policy of IEA Countries: Germany, 2013 Review. International Energy Agency (IEA), Organisation for Economic Co-operation and Development (OECD), Paris pp.200-203, for years 2011 and 2020 predictions.

IEA (2012), IEA Statistics, Statistics by Product, Electricity/Heat. International Energy Agency database. Website: http://www.iea.org/statistics/statisticssearch/report/?country=UK&product=electricityandheat&year=2012 (Accessed in September 2014)

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

IEA (2010), Electricity Information 2010, International Energy Agency (IEA), Organisation for Economic Co-operation and Development (OECD), Paris

IEA (2010b), Energy Policy of IEA Countries: Czech Republic, 2010 Review. International Energy Agency (IEA), Organisation for Economic Co-operation and Development (OECD), Paris

IEA (2010c), World Energy Outlook 2010, International Energy Agency (IEA), Organisation for Economic Co-operation and Development (OECD), Paris

IEA (2010d), Electricity Information 2010, International Energy Agency (IEA), Organisation for Economic Co-operation and Development (OECD), Paris

IEA (2009), Energy Policy of IEA Countries: Belgium, 2009 Review. International Energy Agency (IEA), Organisation for Economic Co-operation and Development (OECD), Paris

IEA (2009b), World Energy Outlook 2009, International Energy Agency (IEA), Organisation for Economic Co-operation and Development (OECD), Paris

IEA (2006): Energy Policy of IEA Countries: United Kingdom, 2006 Review. International Energy Agency (IEA), Organisation for Economic Co-operation and Development (OECD), Paris

IEA (2002), World Energy Outlook 2002, International Energy Agency (IEA), Organisation for Economic Co-operation and Development (OECD), Paris

IEA (2002b), Electricity Information 2002, International Energy Agency (IEA), Organisation for Economic Co-operation and Development (OECD), Paris

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.

IPCC (2013), Climate Change 2013. IPCC Fifth assessment report. The physical science basis.

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.

Minetur (2013) Planificación de los sectores de electricidad y gas 2012-2020. Desarrollo de las redes de transporte. Ministerio de Industria, Turismo y Comercio, Madrid. http://www.minetur.gob.es/energia/es-ES/Novedades/Documents/PlanificacionElectricidadGas_2012_2020.pdf (Accessed 29/11/2013).

Polish Ministry of Economy (2010), National Renewable Energy Action Plan. Warsaw. https://ec.europa.eu/energy/en/topics/renewable-energy/national-action-plans (accessed 15 May 2015).

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.

PT PLN (2013): Rencana Usaha Penyediaan Tenaga Listrik 2012-2021 (RUPTL). http://www.pln.co.id/?p=61 (accessed 26/02/2014).

Red Eléctrica Española (2015), Balance of electrical energy. http://www.ree.es/en/publications/indicators-and-statistical-data/statistical-series (accessed 21/05/2015).

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, JH, Weidema BP, Brandão M (2015). A framework for modelling Indirect Land-Use Changes in Life Cycle Assessment. Journal of Cleaner Production, In press.

SENER (2010), Prospectiva del Sector Elèctrico 2010-2025**,** Gobierno Federal Secretería de Energía, Mexico http://www.sener.gob.mx/res/1825/SECTOR_ELECTRICO.pdf (Accessed September 2011)

Spiegel (2011), A Revolution for Renewables - Germany Approves End to the Nuclear Era. Spiegel 30th of June 2011 Website: http://www.spiegel.de/international/germany/0,1518,771646,00.html (last access August 2011)

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>

Swiss Federal Office of Energy (2013), Botschaft zum ersten Massnahmenpaket der Energiestrategie 2050 (English: Dispatch to Parliament concerning the initial package of measures relating to Energy Strategy 2050). Accessed September 2013: http://www.bfe.admin.ch/themen/00526/00527/index.html?lang=en

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>

Weidema B P, Bauer C, Hischier R, Mutel C, Nemecek T, Reinhard J, Vadenbo C O, Wernet G (2013), Overview and methodology. Data quality guideline for the ecoinvent database version 3. Ecoinvent Report 1(v3). St. Gallen: The ecoinvent Centre.

Appendix: Instructions for importing and using the data in SimaPro

Importing the electricity inventories into SimaPro

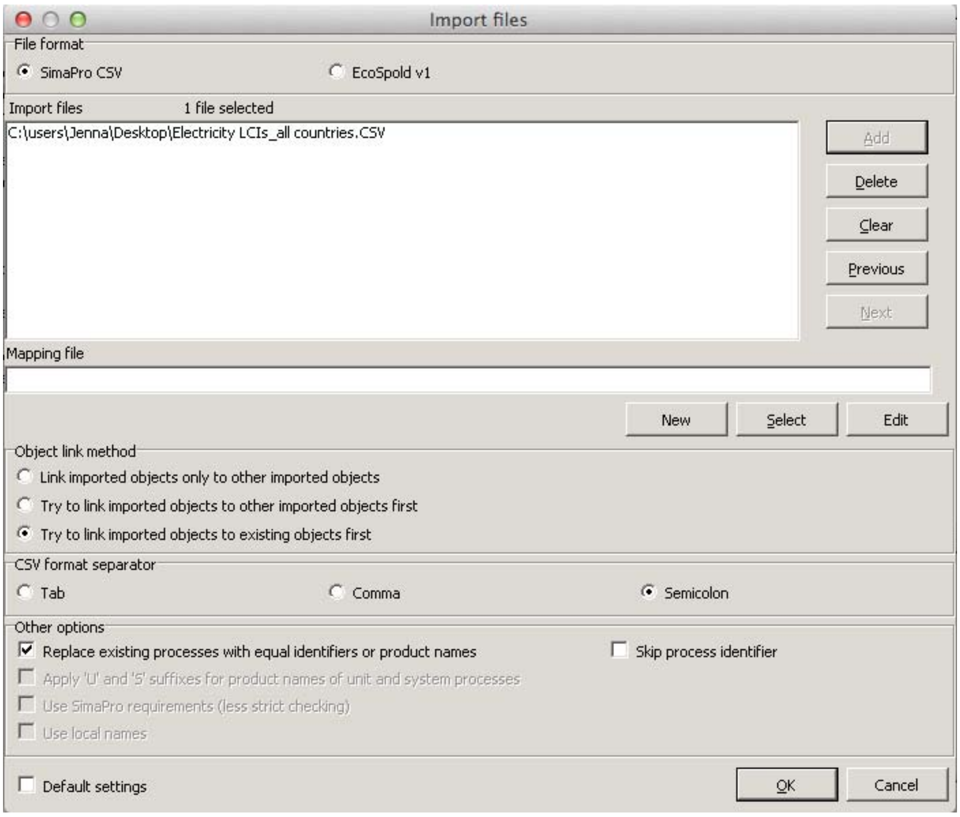
WARNING: this import operation involves replacing several original ecoinvent datasets in the consequential unit process library of SimaPro. This operation cannot be undone.

In order to perform this import, first make sure you have Ecoinvent v3 in SimaPro. The following instructions will allow you to import the electricity inventories as well as the indirect land use change (iLUC) model by 2.-0 LCA consultants, both in their consequential version[1]. The iLUC model is only available to members of the iLUC club (http://lca-net.com/clubs/iluc/).

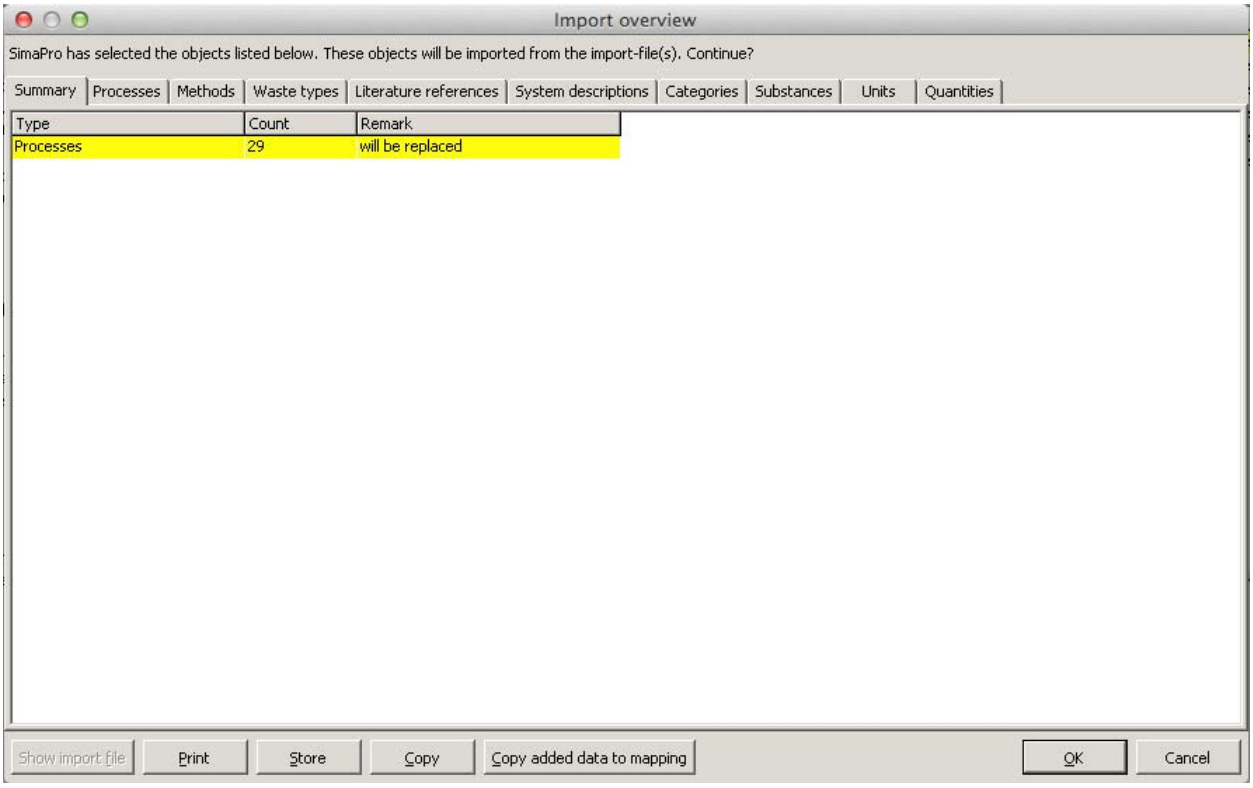
The procedure is as follows:

- Download the CSV file '_CSV_energy club' from the 2.-0 Energy club folder.
- Open SimaPro and the database where you want to import the inventories.
- Go to 'File\Open project\' and open the library project 'Ecoinvent 3 – consequential – unit'.
- Go to 'File\Import\' and the import window will pop up. Click on 'Add' and browse to find the file '_CSV_energy club'.
- The settings for the import operation should be as shown in the screenshot below.

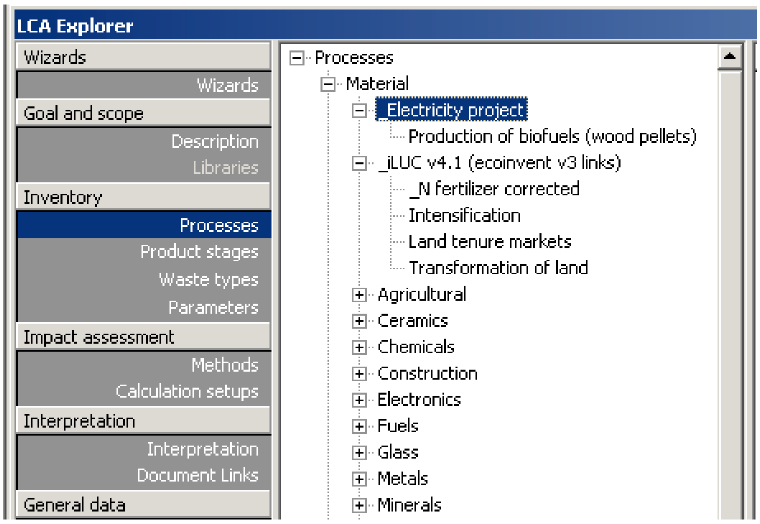
[1] For the attributional modelling of electricity production we rely on the ecoinvent v3 datasets as they are. The attributional version of the iLUC model is not relevant in the inventories you are going to import, as they all refer to consequential modelling.



- Click OK and the import operation will start. After a few seconds the Import overview window will appear, as shown in the screenshot below. The number of datasets to be added or replaced are shown in the summary screen. This screen is for information only. Click OK and the actual import will start.



- Once the import has finished, take a look at the LCA Explorer in SimaPro. Under 'Processes\Material\' you will now have a new folder, '_Electricity project' as shown in the screenshot below. This folder only includes the LCIs associated with production of electricity from biomass. All the remaining inventories are placed in their ecoinvent v3. original location, that is, under 'Processes\Energy\Electricity country mix\'. You will also have a folder called '_iLUC' under the category 'Material'. However, if you are not subscribed to the iLUC club, this folder will contain only empty processes.



Using the inventories in SimaPro

The electricity inventories are designed to work with the use of parameters. You need to create these.

- Go to 'File\Open SimaPro Database\' and open the SimaPro database where you imported the electricity LCIs.
- In 'File\Open Project\' open an existing project where you are working, or create a new one.
- In the LCA Explorer go to 'Inventory\Parameters\' and choose the tab 'Database'. Now you need to create four new parameters or 'switches' (see Scenario switches in SimaPro) related to the electricity inventories, which can alternatively take a value of either 1 or 0:

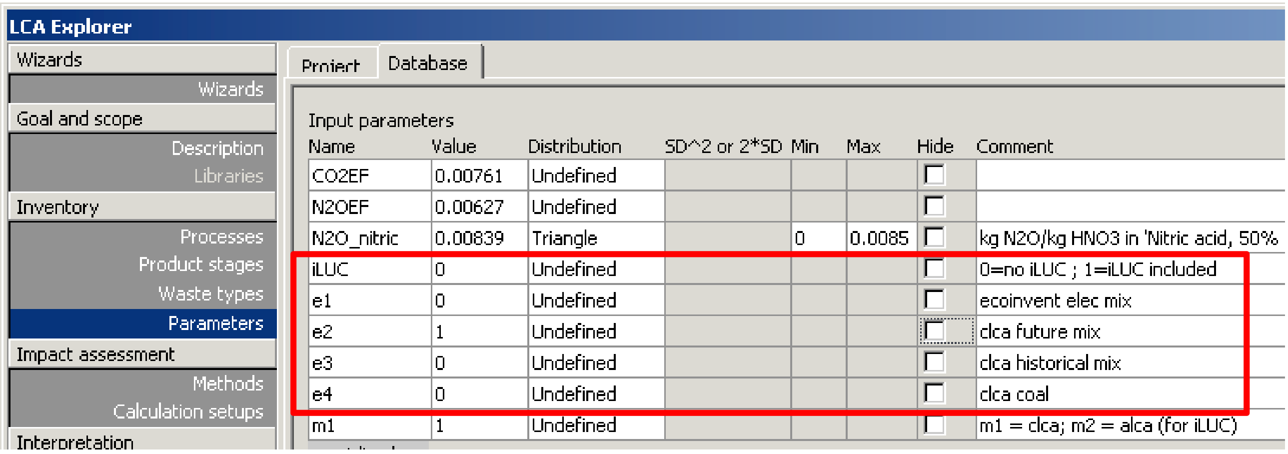
  e1: a value of 1 switches on the default ecoinvent v3 electricity scenario
  e2: a value of 1 switches on the clca_future scenario.
  e3: a value of 1 switches on the clca_historical scenario.
  e4: a value of 1 switches on the clca_coal scenario.
  Important: one of these four switches must have a value of 1, but only one of them at the same time, otherwise the results will be wrong. The remaining three switches must have a value of zero.

- If you imported the electricity inventories including the iLUC model, you need to create three additional parameters related to iLUC:

  iLUC: a value of 1 switches on the consequential iLUC model. With a value of zero iLUC is switched off.
  m1: switches on the consequential version of the iLUC model by using a value of 1. A value of zero switches it off.

m2: switches on the attributional version of the iLUC model by using a value of 1. A value of zero switches it off.

- Once you are done, the parameters should resemble the screenshot below. The comment field is optional but we recommend to write a short explanation like shown here:



- Please remember that each time you change the parameter settings, you need to click on 'Save changes' at the bottom right corner of the Parameters window for the changes to take place.