Challenges of Electricity Production Scenarios Modelling for Life Cycle Assessment of Environmental Impacts

Isabelle Blanc, Didier Beloin-Saint-Pierre

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Abstract

This communication presents a first attempt at making a life cycle assessment of prospective electricity production scenarios which were designed in the EnerGEO project. We start by a basic review of system (in this case, scenario) modelling expectations in today's LCA study. We then review some of the challenges of implementation due to the lack of detailed description of present and future electricity production systems. The importance of a detailed description is then shown with an evaluation of uncertainty of life cycle impact assessment results for three scenarios of German electricity production in 2030. The significant uncertainties we found, prevent us from detecting a relevant trend or making any comparison between the three chosen scenarios. We finally come to the conclusion that the LCA methodology will become relevant for the environmental assessment of electricity production scenarios when many more detailed information are accounted to describe future technologies, structures and sources of energy.

1. Introduction

Recognizing the strong need for an assessment of current and future impact of energy use on the environment, the European Union, with the help of the EnerGEO project, has tried to enable the linkage of large-scale energy models projecting medium-run to long-run developments with more detailed models to contribute to the improvement of projections, policy recommendations, and environmental assessments. One of those more detailed models is the Life Cycle Assessment (LCA) method which is under study in the EnerGEO Platform of Integrated Design (PIA) (Blanc/Gschwind/Lefevre/Beloin-Saint-Pierre/Ranchin/Ménard/Cofala/Fuss/Wyrwa/Drebszok/Stetter/Schaap 2013). This article explores the implementation of the LCA method for medium-run to long-run electricity production scenarios.

2. Electricity production modelling within the LCA framework

Many "processes" of the human activities need to be considered when we want to assess the life cycle environmental impacts of electricity production for a country in a given year. In fact, the amount of data that needs to be treated is so important that most LCA analyst are using database, at least for background data.

A detailed and comprehensive example of how electricity production systems are modelled can be found in documents which describe the ecoinvent database (Dones/Bauer/Bolliger/Burger/Faist Emmenegger/Frischknecht/Heck/Jungbluth/Röder/Tuchschmid 2007). LCA studies of energy systems have also been the focus of several publications (Pehnt 2006), (Sorensen 2011) and highlighted common sources of environmental impacts for such systems. All those documents are a good source of information to make specific case studies (scenarios) of electricity production and then to assess their life cycle environmental impacts. Those scenarios can then represent the deployment of different energy structure in the future of different countries. However some challenges of life cycle modelling for existing electricity production mix and future scenarios are now highlighted.

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2.1. State-of-the-art LCA modelling of electricity production systems

With today's tools (software and databases), modelling a country's electricity production system within a life cycle perspective requires, at the very least, an account of energy sources proportions, infrastructures' power output, lifetime, natural resources transport distance and extraction of resources. Figure 1 summarizes how some "processes" are linked together when the life cycle of electricity production is modelled for the ecoinvent database. The proportions are based on national and international statistics gathered by ecoinvent analysts and serve as a representation of the existing electricity mix assessed in this paper. Figure 1 is only a partial representation of the disaggregation level of the "processes" which describe the full system. In fact, the variability of the infrastructures' power output is not shown for comprehensiveness purpose. In total, the ecoinvent database lists 2000 "processes" to describe the full life cycle of this system. Each of the "processes" is described by hundred or even thousands of information in a specific datasheet. This gives an idea of the complexity and amount of data that needs to be treated for system modelling in LCA studies of electricity production.

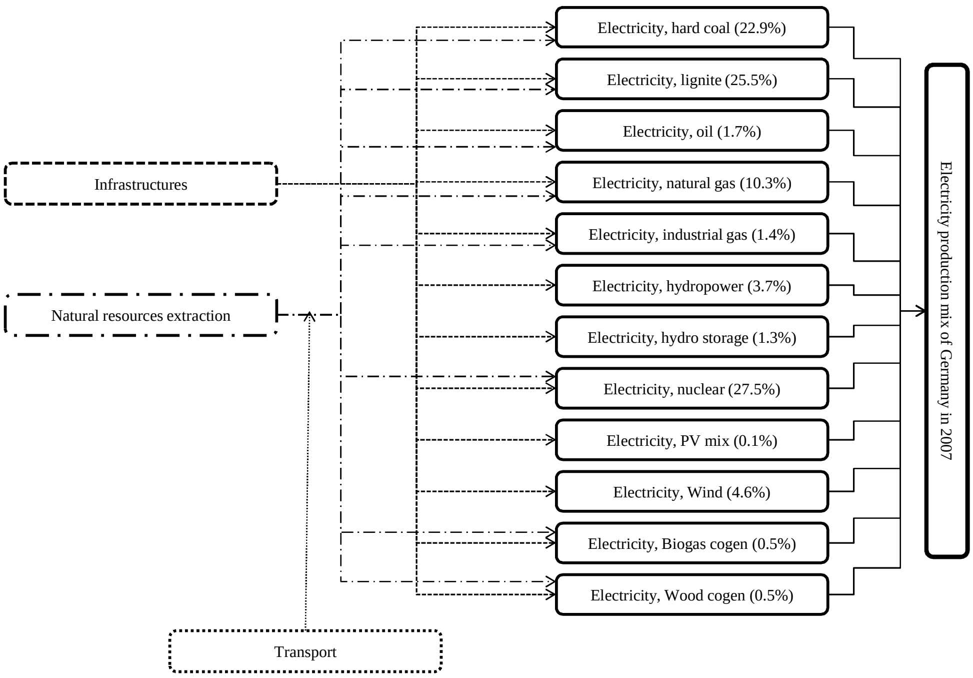

Figure 1
Description of some of some aggregated "processes" involved in the life cycle of producing electricity in Germany for 2006

In the case of the ecoinvent database, the sources "processes" are defined through different technologies and infrastructures with available data. Sometimes, "proxies" are used to describe a technology which is not exactly representative of what an analyst intends to model. For example, the dams which are part of the hydroelectricity production in Germany are modelled from the Swiss data in the ecoinvent database since more representative information is unavailable. In addition, some database specific standards define the average transport of natural resources and electricity for each country. Those example show that the search for precision in describing system with the LCA methodology comes with a cost in uncertainties with the values that are used to model systems.

2.2. LCA modelling of future electricity production in EnerGEO

The task of modelling scenarios for future electricity production systems follows the same methodology as implemented in the ecoinvent database but data must be replaced in order to account for technology and infrastructure which are specific to the EnerGEO scenarios (Blanc/Gschwind/Lefevre/Beloin-Saint-Pierre/Ranchin/Gschwind/Ménard/Cofala/Fuss/Wyrwa/Drebszok/ Stetter/Schaap 2013).
To perform a LCA modelling within the EnerGEO project, we modelled the structure of energy sources by countries according to the TRANS CSP scenarios (Trieb *et al*, 2006, Trieb *et al*, 2012) for three scenarios: "Island Europe", "Open Europe" and "Max Renewable". The main characteristic of "*Island Europe*" scenario is a high share of power generation from renewable sources but no imports from outside Europe; missing electricity will mostly be generated by nuclear plants. The "*Open Europe*" scenario assumes imports of solar energy from North Africa, high renewable energy share in electricity generation, and phase-out of nuclear energy. The "*Maximum Renewable Power*" scenario assumes the highest possible electricity generation from renewable sources.

The distributions of energy sources used for the German mix in 2030 for all three scenarios are presented in table 1. Values of the 2006 German electricity mix (from ecoinvent 2.2) are presented as a reference.

Table 1
Distributions of energy sources to produce electricity in Germany in 2030 for each TRANS CSP scenario

	Scenarios for GERMANY			
Energy sources	Island EU 2030 TRANS CSP	Open EU 2030 TRANS CSP	Max Renew 2030 TRANS CSP	Reference 2006 Ecoinvent2.2
Nuclear	12%	0%	0%	27%
Hydroelectricity	4%	4%	4%	5%
Wind	34%	36%	33%	5%
Solar	5%	5%	5%	≈0%
Biomass	10%	10%	10%	1%
Geothermal	1%	1%	2%	0%
Coal	22%	25%	28%	48%
Oil	0%	0%	0%	2%
Gas	13%	11%	8%	12%
Importation others	0%	0%	0%	0%
Importation solar	0%	9%	11%	0%

The values presented in table 1 do not meet the usual level of detail that is required for system modelling within a LCA study. This lack of information brought a need for many assumptions in order to model the life cycle of those three German scenarios. The following list presents some of the modelling assumptions that have been made in our study. Most of them correspond to temporary solutions which will be replaced once relevant data has been identified. Such modelling assumptions might induce a fairly low level of representativity of the 2030's situation:

- Percentages of technology used by each source are based on the reference year of 2006 and ecoinvent information (Dones/Bauer/Bolliger/Burger/Faist Emmenegger/Frischknecht/Heck/Jungbluth/Röder/Tuchschmid 2007):
  - Type of nuclear power plant;
  - Proportions between run-of-river and dam hydroelectricity power plants;
  - Power output (size) and onshore or offshore installation share for wind turbines;
  - All of solar electricity is produced by photovoltaic technology;
  - Etc...
- No information on how technology would change between today and 2030 has been found for those particular scenario and we made the cautious hypothesis that all electricity production technologies would be equivalent to the one of the 2006 reference year;
- There is no available data on geothermal energy in the ecoinvent v.2.2 database (used to model the electricity production scenarios) which means that we had to neglect that source;
- The solar energy importation systems have been estimated to be equivalent to the photovoltaic systems used in Germany because of the lack of Concentrating Solar Power (CSP) model in ecoinvent 2.2 version;
- The infrastructure for electricity production and transportation is not modified between 2006 and 2030.

3. Life Cycle Assessment results for the electricity production scenarios in Germany

We now present the carbon footprint results of the full life cycle impact assessment for our studied country, Germany, to show the interest and main difficulties in making LCA studies of electricity production scenarios. Figure 2 presents the greenhouses gases (GHG) in grams of CO_2 equivalent per kWh for electricity produced by the three prospective scenarios as well as the ecoinvent 2006's reference.

If we accept the previous assumptions as representing the 2030 situation, GHG associated to the 2006 reference scenario are significantly higher by approximately 20% to any of the three others scenarios showing the interest of such new prospective scenarios compared to the current situation despite the associated inherent uncertainties. We applied the ecoinvent methodology (Frischnecht /Jungbluth/Althaus/Doka/Heck/Hellweg/Hischier/Nemecer/Rebitzer/Spielmann/Wernet 2007) to assess uncertainties of the modelled system Using the uncertainty assessment for input data, given in the ecoinvent database, coupled to a Monte Carlo uncertainty calculation (implemented in the Simapro PhD 7.2 software) allows us to obtain the uncertainty range for all scenarios results as reported in figure 2. These uncertainties ranges are between -22% to +25% for the three studied scenarios while being between -9% to +9% for the ecoinvent reference scenario. The scenarios uncertainty ranges are therefore more than twice higher than the ecoinvent one. This can explained by the values we gave to characterize the input uncertainties in what is called the pedigree Matrix (Weidema/Wesnæs 1996). This pedigree matrix in ecoinvent (Frischnecht/Jungbluth/Althaus/Doka/Heck/Hellweg/Hischier/Nemecer/Rebitzer/Spielmann/Wernet 2007) covers six characterizations: the reliability, the completeness, the temporal correlation, the geographical correlation, the technological correlation and the sample size. For the EnerGEO scenarios we had to change the temporal correlation factor from 1 (most certain level) to a value of 5 (most uncertain level) for all the proxy "process" we have defined.

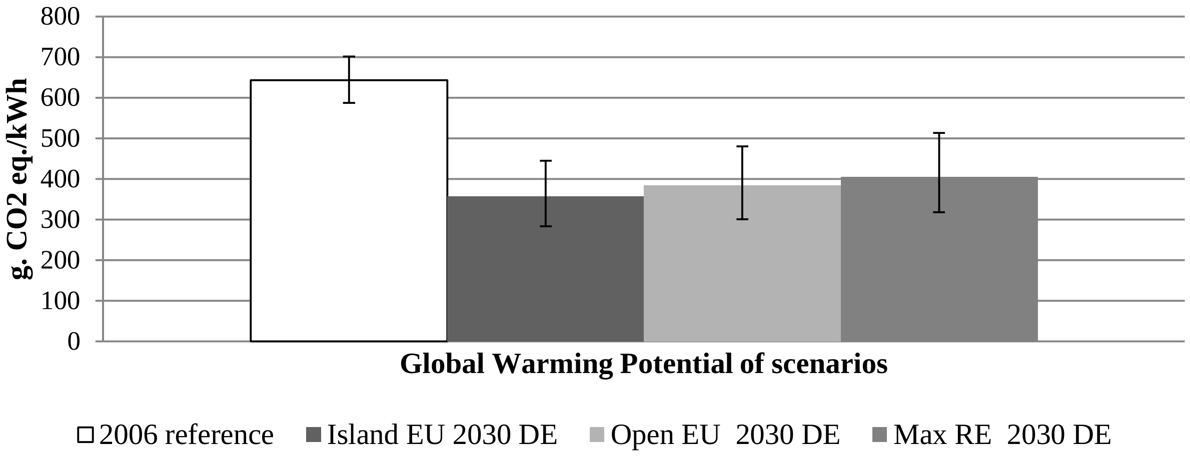

Figure 2
Carbon footprints of the German electricity mix scenarios of the TRANS CSP model for the year 2030 Reference value for 2006 serves as a basis of comparison. The minimum and maximum of uncertainty bars are there to represent the 2.5%-97.5% confidence interval of the uncertainty distributions.

The carbon footprint values presented in figure 2 present an unexpected trend between the scenarios. Indeed, scenarios including a higher rate of renewable energy show higher life cycle environmental impacts: a preferable course would be to follow the Island Europe option with a higher share of gas and nuclear sources. In fact, the Island Europe scenario is reducing quite significantly the coal share which explains such trend. However this trend cannot be confirmed since the uncertainty ranges over the scenarios results are exceeding the difference between the scenarios. It therefore means that they should all be considered equivalent considering the knowledge we have today to describe and to model those electricity production systems at the 2030 horizon.

4. Conclusions

The approach to life cycle assessment modelling of prospective electricity production scenarios that we present here is a first trial. It mainly serves as an example to show some of the difficulties in modelling future systems at a high level of detail. The lack of detailed descriptions and LCA modelling for any of the scenarios explains the high uncertainties associated to the evaluation of the carbon footprints. Recognising these high uncertainties prevent us from establishing any relevant trends when comparing the scenarios. Furthermore such analysis needs to be extended to other impacts to enlarge the assessment for a multi criteria one which would be more valuable when considering any decision making.

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