Meeting the NEEDS of European environmental sustainability assessment

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ABSTRACT

Mixing LCI data from databases representing today's situation with LCI data for energy systems and technologies that will only be realised in some decades from now leads to results that do not well represent the environmental impact of the intended future situation. This is the more true for technologies with low or zero direct emissions such as wind, or photovoltaic. Within the European NEEDS project, the environmental efficiency of the production of selected relevant commodities are adapted to a 2025 and 2050 situation. Using background data based on unit processes a change in selected datasets propagates into every dataset. This improves accuracy and consistency of the resulting product systems substantially. In the NEEDS project the future energy mix including a share of these new technologies is taken into account as well as changes in the mining, materials and transport sectors. It is shown that a consistent modification leads to results that are significantly different from those using unmodified data.

INTRODUCTION

The environmental assessment of energy systems has long traditions in the fields of life cycle assessment, technology foresight, external costs and energy planning. However, research in these areas was performed more or less in isolation with little interaction between the research communities. For a long time, the large synergy potentials remained either undiscovered or were not exploited to an extent worth mentioning. But a few years ago, leading research institutes realised the disproportional knowledge gain of combining life cycle assessment, technology foresight, external cost assessment and energy modelling. They formulated the research project NEEDS (**N**ew **E**nergy **E**xternalities **D**evelopments for **S**ustainability), that was selected and funded within the 6th EU framework program.

GOAL AND SCOPE OF THE RESEARCH PROJECT

The future developments of energy systems, in particular electricity generating technologies, are in the focus of the research project. Assessing the environmental impacts of new and potentially promising technologies based on their performance of today and based on today's economies entails severe drawbacks and may ultimately lead to suboptimal decisions in energy policy. The conversion efficiency of fuel cells or the material efficiency of solar cells may dramatically increase in the coming decades. The environmental performance of manufacturing steel, aluminium or cement and of providing transport services by lorries will further improve in the future. Finally, to achieve the European Commission's CO_2 reduction target, the electricity mix in Europe will change and include more and more electricity from renewable sources [1, 2]. The NEEDS project aims at taking all these developments into account when assessing the environmental performance of long term future electricity generating technologies. The outcomes of the research project are intended to help the European Commission and individual countries in their long term energy supply policy.

The objectives and targeted innovations are the following:

- *Life cycle assessment (LCA):* time and scenario dependent life cycle assessments of emerging electricity supply technologies, taking into account the future developments in the technology itself, in the materials supply, transport and electricity supply sectors
- *External costs:* Monetary valuation of externalities associated to energy production, transport, conversion and use, including impacts so far insufficiently addressed (like for instance land use)
- *Energy modelling:* integrating external cost and life cycle assessment information into a consistent and robust Pan-European energy model framework.
- *Acceptability and stakeholder perspective:* identify terms and conditions for an effective implementation of longterm energy policies based on internalised external costs. Examine the robustness of the outcomes under various stakeholder perspectives

- *Transferability and generalisation:* develop a simple way of calculating, transferring and present default values for average/aggregated external costs
- *Integration:* develop a structured "protocol" to facilitate the widespread use of the integrated analysis framework

THE SYNERGIES OF INTERACTION

Four main areas join together: life cycle assessment, technology foresight and learning curves, external costs assessment, and energy modelling. The first link (Number 1 in Fig. 1) between life cycle assessment and technology scenarios combines the techniques of technology forecast and learning curves to specify the expected improvements in electricity generating technologies. The life cycle inventory results of electricity produced with a future technology will be distinctly different from the ones of electricity provided by a similar technology today.

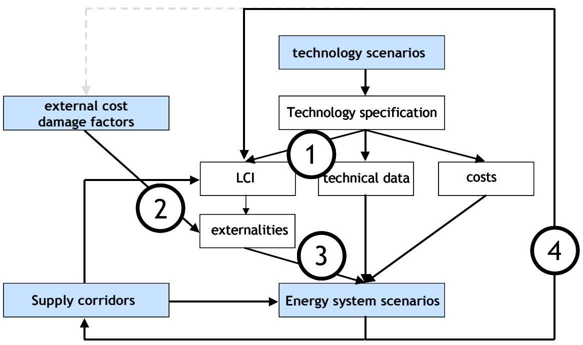

Fig. 1 Interactions between the different disciplines in the NEEDS project

The cumulative environmental impacts (external damage costs) are then calculated by combining life cycle inventory results (e.g. kg SO_2 emitted per kWh electricity) with external cost damage factors (e.g. Euro damage costs per kg SO_2 emitted; Number 2).

Those external cost figures (Euro-Cents per kWh electricity) are then embedded into the Pan-European energy model (Number 3). The outcomes of the energy model are future optimal energy supply mixes given a distinct economic development (economic growth rate, oil price development, etc.), developments of (private and external) costs of electricity supply technologies and eventual constraints (capacity constraints, CO_2 emission targets, etc.). An optimisation based on energy models that includes internalised external damage costs will result in distinctly different "ideal" energy supply mixes as compared to optimisations based on private costs only. One of the results of the energy modelling, namely the "optimal" European electricity mixes, are used in the background system of the life cycle assessments. The life cycle inventory results of electricity generating technologies depend to a variable degree on the changes predicted in the European electricity mix. With that the circle of interactions is closed.

The interactions described above allow for more comprehensive, more consistent and more accurate quantification of
- the environmental impacts of background system in life cycle assessments,
- the external environmental damage costs of future electricity generating technologies, and
- the optimal future energy supply situation

valid for different scenarios and different future time horizons.

In order to limit computing time and working efforts, the NEEDS project partners agreed on three technology scenarios and three time horizons. The scenarios applied on the life cycle inventories are the following:
- *pessimistic:* Socio-economic framing conditions do not stimulate market uptake and technical innovations
- *realistic-optimistic:* Strong socio-economic drivers support dynamic market uptake and continuous technology development. It is very likely that the respective technology gains relevance on the global electricity market
- *very optimistic:* A technological breakthrough makes the respective technology on the long term a leading global electricity supply technology

The scenarios are quantified for 2025 and 2050. In addition to that, the state of today is represented as the starting point common to all three scenarios.

LIFE CYCLE ASSESSMENTS OF FUTURE ELECTRICITY GENERATING TECHNOLOGIES

Within the NEEDS project, the environmental efficiency of the production of selected relevant commodities are adapted to a 2025 and 2050 situation based on extrapolating existing technologies (eventual technology breakthroughs are not considered):
- Materials: aluminium, copper, nickel, iron, steel, MG-silicon, zinc, clinker (cement), flat glass
- Transport systems: lorries and van
- Electricity mix: European (UCTE) mix
- Electricity generating technologies

The electricity generating technologies comprise the following:
- advanced fossil: hard coal, lignite, natural gas, including carbon capture and storage
- fuel cell: MCFC, PEMFC, SOFC
- offshore wind: 2 to 32 MW engines
- photovoltaics: cristalline and thin film technologies
- concentrating solar thermal:, trough and tower
- biomass: straw and poplar
- advanced nuclear: generation III and generation IV light water reactors
- wave energy: wave dragon

The unit process data of the ecoinvent database with their detailed documentation allows for an efficient adaptation. That is why ecoinvent data v1.3 [3] was chosen as the common background database not only for the materials and transports but also for some of the electricity generating technologies (such as the nuclear fuel cycle). This database allows for individual changes on a unit process level due to its transparent structure and reporting [4, 5]. The underlying modelling principles and data format (EcoSpold format, [6, 7]) are used by all partners of the EU project. Only the most relevant datasets are forecasted into the future. The changes, however, will first of all propagate into all other datasets of the background database and secondly into the electricity generating systems to be evaluated. The calculations are performed with Umberto 5.5 [8].

Four sectors contribute to the change in emissions and resource consumptions in the future, namely:

- material supply,
- lorry and railway transport,
- electricity supply mixes, and
- electricity generating technologies.

The environmental performance in the four sectors will develop according to the scenario chosen. That is why they are combined to one consistent set of LCI data of the situation in an economy in 2025 and 2050. The NEEDS project thus produces seven life cycle inventory databases consisting of unit processes valid for 2000, 2025, and 2050 reflecting the three scenarios "pessimistic", "realistic-optimistic" (RO) and "very optimistic".

RESULTS

This section shows the results of the realistic-optimistic scenario and its time horizons 2025 and 2050. The 2050 scenario results base on three different electricity mixes with technology shares as shown in Tab. 1. Four selected elementary flows (fossil CO_2, NO_X, and C-14 emitted to air, as well as oils emitted to water) are used to show the overall effects of the technology developments described above.

Tab. 1 Electricity mixes of 2000 and in the future (440ppm and renewables scenario)

[%]	today	440ppm	renewables
fossil	46.8	54.3	19.6
nuclear	35.7	23.3	0.0
hydro	15.7	19.0	24.3
new renewables	1.8	3.4	56.1

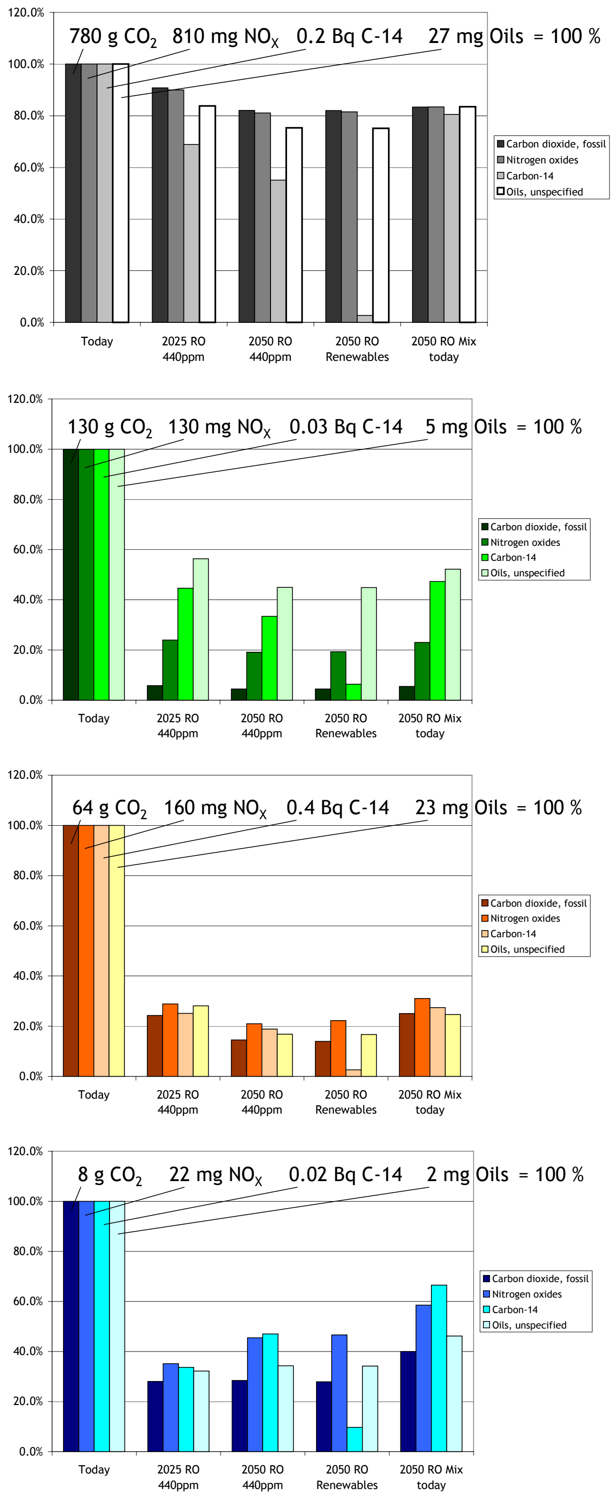

Fig. 2 Evolution of selected cumulative emissions of electricity from IGCC hard coal, solar thermal, PV, and wind.

Coal power will reduce its CO_2 and NO_X emissions by 20 % only, while the C-14 emissions may be reduced by more than 95 % in case of a renewables based electricity mix. Solar thermal electricity shows considerably lower CO_2 and NO_X emissions in the future due to the replacement of the current natural gas fired back-up turbine by latent heat storage facilities. C-14 and oil emissions can be reduced to less than 50 % of today's emissions. The reduction potential of single cristalline silicon cells is as large as about 80 % of its current emissions. Wind power can reduce fossil CO_2 emissions by about 75 %. NO_X emissions tend to increase again beyond 2025 after a reduction by 65 % in the coming 20 years. This is due to a change in design.

The specific emission levels as of today are of interest besides the predicted relative improvements during the coming four decades. Today, hard coal based electricity emits about 6, 12 and 100 times more CO_2 as compared to today's electricity from solar thermal, single cristalline PV and wind, respectively. According to our modelling results, this significant difference will even increase in the future.

CONCLUSIONS

Scenario and time dependent LCA datasets of selected material supply, transport service and electricity generating technologies are available. Data are published via the NEEDS website and using the EcoSpold format, the most widespread and accepted LCI data format worldwide.

Preliminary assessments lead us to the following conclusions:

- Operation-intensive power plants (e.g. fuel based power plants such as the IGCC hard coal power plant) are influenced to a low extent by background processes. Direct improvements in power plant technology (e.g. carbon capture and storage) are far more important.
- material-intensive power plants (e.g. those harvesting solar energy) are influenced to a high degree by background processes. Hence, not only direct technological progress such as cell efficiency but also improvements in the industrial production system as a whole propagate into the results of these technologies.
- Updating background data significantly improves the accuracy of results of future systems – in particular when the main share of the environmental impact stems from the production or construction
- Updating background data is of primary importance when different future electricity generation technologies are compared and some of the technologies are operation- and others are production-intensive.
- Neglecting the effect of changes in the background data can lead to significant overestimations and, hence, to misleading results and conclusions.
- A background database built on well and transparently documented unit process datasets is a prerequisit for long term environmental sustainability assessment of technologies and makes the update work a very straightforward task.
- Long-term environmental technology assessment studies should thus avoid the use of fixed and unchangeable rolled-up (cumulative) LCI background data that describe the situation of today (or even the recent past) because it is very likely, that the results of such studies are strongly misleading and biased.

REFERENCES

[1] European Commission, European Energy and Transport - Scenarios on energy efficiency and renewables, Office for Offical Publications of the European Communities, Luxembourg, http://ec.europa.eu/dgs/energy_transport/figures/scenarios/doc/2006_scenarios_on_energy_efficiency.pdf, 2006

[2] Krewitt W., Simon S., Graus W., Teske S., Zervos A. and Schäfer O., The 2 °C scenario - A sustainable world energy perspective. Energy Policy, 2007. 35, pp. 4969-4980

[3] ecoinvent Centre, ecoinvent data v1.3, Final ecoinvent reports No. 1-16, Swiss Centre for Life Cycle Inventories, CD-ROM No. ISBN 3-905594-38-2, Duebendorf, Switzerland, www.ecoinvent.org, 2006

[4] Frischknecht R., Jungbluth N., Althaus H.-J., Doka G., Dones R., Heck T., Hellweg S., Hischier R., Nemecek T., *et al.*, The ecoinvent Database: Overview and Methodological Framework. Int J LCA, 2004. 10(1), pp. 3-9

[5] Frischknecht R., Transparency in LCA – a heretical request? Int J LCA, 2004. 9(4), pp. 211-213

[6] Hedemann J. and König U., Technical Documentation of the ecoinvent Database, Swiss Centre for Life Cycle Inventories, Institut für Umweltinformatik, Hamburg, DE, CD-ROM No. Final report ecoinvent 2000 No. 4, Dübendorf, CH, www.ecoinvent.org, 2003

[7] Frischknecht R. and Rebitzer G., The ecoinvent database system: a comprehensive web-based LCA database. Journal of Cleaner Production, 2005. 13(2005), pp. 1337-1343

[8] ifu and ifeu, Umberto - the software for process optimisation; version 5.5, Software, Manual & Appendices, Hamburg, Heidelberg, 2006

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