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Environmental assessment of future technologies: how to trim LCA to fit this goal?

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Abstract
Introduction New and innovative technologies may claim substantial efficiency gains in the future. However, they are often assessed based on their current performance, measured in the laboratory or in pilot plants. The goal of discussion forum 38 was, on one hand, to shed light on the main drivers and principles that ensure a sensible and fair assessment of far future technologies. On the other hand, the most recent European developments in prospective technology assessment of emerging energy technologies and the related quantification of external costs were touched upon.
Discussion The discussion forum started with three talks dedicated to external costs and multicriteria decisions presenting results of the New Energy Externality Developments for Sustainability project. After three presentations considering long-term LCI modeling aspects, lectures were held covering industry implementation and case studies. The following main conclusions were drawn at the end of discussion forum 38: (a) life cycle assessment (LCA) is considered a useful tool for environmental assessments of future energy technology, (b) consistency in LCA modeling of future situations is achieved by adapting data in the foreground (electricity-generating technology) and in the background (electricity supply mix, material manufacture, transport services, etc.), (c) external cost assessments and multicriteria decision analysis involve value judgments and thus do lead to a variety of different conclusions, (d) the present situation must be known properly to be able to model possible future situations, and (e) challenges are the data availability and definition of consistent scenarios of the future.

Keywords Electricity-generating technologies · Emerging energy technologies · Future technologies · Long-term LCI modeling · NEEDS project · New Energy Externality Developments for Sustainability project · External cost assessment

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1 Introduction

New and innovative technologies have to compete with well-established and mature technologies. Even though new and innovative technologies may claim substantial efficiency gains in the future, they are often assessed based on their current performance, measured in the laboratory or in pilot plants.

Thus, the environmental assessment of such future technologies faces several challenges. Firstly, the performance and efficiency of operational-scale technologies will differ from those of laboratory-scale or pilot-scale equipment or from performance and efficiency figures gained with process modeling. Secondly, the basic economic, environmental, and social conditions will change with time and thus will differ from the basic conditions of our current economy, environment, and society. Neglecting such expected changes in the environmental assessment of future technologies may lead to a severe impediment for the market entrance and growth of promising future technologies. Thirdly, the predictions of technological, societal, economical, and environmental developments are inherently uncertain and, therefore, subjected to dispute.

Within the New Energy Externality Developments for Sustainability (NEEDS) project (6th Framework Program of the European Commission, NEEDS 2009) on the improvement of the assessment of external costs of electricity supply, experiences were gained in the field of long-term prospective environmental technology assessment with the help of life cycle assessment (LCA).

The goal of the Swiss LCA discussion forum 38 was, on one hand, to shed light on the main drivers and principles that ensure a sensible and fair assessment of far future technologies. Representatives from national and international companies showed their approach in long-term strategic planning and the potential role of LCA. On the other hand, the most recent European developments in the identification of specific external damage costs per kilogram resource extracted and pollutant emitted were touched upon. The discussion forum 38 especially focused on the role of and requirements on LCA in long-term future technology assessment.

2 External costs and multicriteria decisions

The discussion forum was opened by Rolf Frischknecht (ESU-services Ltd.) with an overview of the NEEDS project. The goals of NEEDS covered the evaluation of the full costs and benefits of electricity supply considering three scenarios based on energy policy and three time horizons (2000, 2025, and 2050). The external costs were calculated for the level of individual countries as well as the enlarged European Union.

The first session was dedicated to external costs and multicriteria decisions containing three presentations of research performed within the NEEDS project. Wolfram Krewitt (DLR) illustrated the external cost assessment of future electricity supply systems. At the beginning, he focused on the question whether or not external costs were robust enough to steer decision processes. Some external costs, e.g., of the damage to building materials and change in agricultural yield can be quantified relatively accurately, but they are very low compared to private costs. Other external costs, as, e.g., climate change impacts, are significant and quantified with large variability (up to a factor of 100) due to the diverging preferences the decision-makers express. Diverging preferences include, e.g., discounting of future damage and the application of purchasing power parity. A better understanding about which externalities can be reasonably quantified and used for supporting decision-making needs to be developed. The second part of the presentation focused on the question if external cost information sufficiently represents long-term dynamics to support long-term strategy development. A dynamic LCA is necessary to consider future aspects in technology development. The future development of technologies depends on socioeconomic framing conditions; therefore, three scenarios are set up. Examples of external costs for today and 2050 are given for various technologies. The results showed that emerging energy technologies have a significant potential to reduce costs and environmental impacts and that external costs of future renewable energy technologies are small. A key for supporting prospective technology assessment is the application of dynamic LCAs as developed within the NEEDS project. Furthermore, external costs are helpful to make a quantitative link between environmental impacts and welfare losses. Nevertheless, nonquantifiable externalities still exist and most probably will still be missing in the future. The presenter outlines that policy decisions should be guided by the precautionary principle rather than waiting for scientific evidence that can prove a cost-optimal strategy.

Walter Ott (econcept) presented an assessment of the external costs of biodiversity losses due to land use transformation by energy production and energy-related airborne emissions. The methodological approach is based on the Eco-Indicator 99 (Goedkoop and Spriensma 2000) model using the damage measure “potentially disappeared fraction (PDF)” whereby the biodiversity loss is quantified as ΔPDF. The monetary value of biodiversity loss due to land use changes is achieved by a restoration cost approach. Restoration costs are defined as the costs incurred by the measures necessary to establish a target habitat. Biodiversity losses due to energy-related airborne emissions are quantified via the effects of acidification and eutrophication due to NO_X, SO_X, and NH_3 depositions. The costs of biodiversity damage due to airborne emissions are calculated with the restoration costs for land use changes from unsealed natural areas with relatively low biodiversity into natural areas with high biodiversity. The resulting external costs for Switzerland concerning airborne emissions deposited amounts to 0.46€/kg SO_X and 8.33€/kg NH_3. However, future restoration costs due to land use changes and damage costs of airborne emissions depend on many factors. The presenter emphasized that the results fit best for central Europe and that the restoration costs are based on various willingness to pay studies which may change in the future when the availability of natural areas changes.

Stefan Hirschberg (PSI) focused on the comparison of total social cost assessment and the multicriteria decision analysis (MCDA) applied on power systems. The aims of the project were to broaden the basis for decision support by examining the robustness of results including various stakeholder perspectives and to explore stakeholder perspectives on external costs. Two approaches are presented and compared, namely, the total social costs approach (external + private costs) and the MCDA. The externality concept is generally accepted by the stakeholders even though controversial results may follow especially in the case of nuclear power and with regard to climate change. Theoretically, any externality can be monetized; however, in practice, methodologies and valuation are often controversial. MCDA is developed as an aid to thinking and decision-making. The method does not provide one single answer but allows for several answers depending on stakeholders, criteria, and interests. In MCDA, a set of environmental, economical, and social indicators is chosen by involving the stakeholders. The comparison of the two approaches showed that total social cost favors nuclear and disfavors biomass energy technologies. The ranking of fossil technologies in comparison to improved solar and wind power technologies very much depend on the external cost value chosen for greenhouse gas (GHG) damages. The MCDA approach generally favors renewable energy technologies while coal technologies perform worst. Inclusion of a wide set of social criteria disfavors nuclear energy. The results of the MCDA depend on the emphasis on environmental (penalizes fossil technologies), economic (penalizes renewable technologies), or social (penalizes nuclear technologies) conditions.

3 Long-term future LCI modeling aspects

In the second part of the discussion forum, it was shown how life cycle inventory (LCI) modeling deals with long-term issues. Rolf Frischknecht (ESU-services Ltd.) focused on the challenges of including future energy technologies in LCIs based on work done within the NEEDS project. The challenge lies in the combination of relevant knowledge for environmental sustainability assessments. Modified LCIs of metals, mineral-building materials, transports, and electricity mixes were used to establish future LCI product systems of electricity generation technologies using the international, transparent ecoinvent data v1.3 (ecoinvent Centre 2006) as the starting point. In this way, the consistent modeling of the interdependencies between energy generation, material production and transport, technologies, and the possible future scenarios is ensured. LCI results of various technologies for the year 2000, 2025, and 2050 are shown, whereby the improvement potential until 2050 is between 20% and more than 90% compared to the situation in the year 2000. The results further showed that operation-intensive systems show less improvement potentials, unless end-of-pipe technologies are installed (carbon capture and storage) and that some technologies may outperform others in the future (photovoltaic versus wood). In some cases (offshore wind power), an increase in emissions is expected after 2025 due to a change in the design of the plant and the fact that less optimal locations are to be chosen. It is shown that if electricity mix developments are not included, results change considerably. It is concluded that life cycle thinking is indispensable in long-term energy policy, that the technology development needs to be considered in the background data, and that possible future scenarios should be included in energy policy and environmental sustainability assessments. As LCA is able to adopt these requirements, it is considered a useful tool for environmental sustainability assessments of future technologies.

Matthias Galus (ETH Zurich) talked about integrated modeling and analysis of power and transportation systems applying the energy hub concept. Energy hubs depict possible future energy systems with interconnected multiple energy carriers. An example is shown of modeling plug-in hybrid electric vehicles (PHEVs)/electric vehicles (EVs) in future power systems whereby a hub system models a city. This model approach requires power systems, transportation, and vehicle fleet simulations. The current layout of the project does not include future scenarios of, e.g., different possible trends in private transportation behaviors. At the end, the presenter raised up some questions which could be handled in LCA, such as the possible integration of smart grid associated with PHEV and the sustainability of PHEV/EV compared to combustion vehicles.

Marloes Caduff (EMPA) presented her Ph.D. work about integrating technical scaling laws into LCA. Scaling laws are expressed as a power law: $y=a\times x^b$ whereby b is the scaling factor. Five hundred cases of industrial equipment are investigated whereby volume, fuel use, and power output are considered. The results showed that a scaling factor exists, which should not be neglected by LCA practitioners. A relatively good correlation results for engines production (global warming potential versus power capacity) but the correlation gets less clear considering engines operation due to efficiency decrease. For infrastructure manufacture a “rule of thumb” was established where the scaling factor b is 0.65. A scaling factor may be developed for every single input, for processing materials, or for whole groups, e.g., plastics, infrastructure, energy, etc. However, the integration of scaling factors in LCA requires parameterized modeling.

4 Industry implementation and case studies

The afternoon session was opened by Walter Graenicher (Alstom) discussing long-term power generation visions in the context of economical and political realities. He showed statistics of the global electricity market and future perspectives from an industrial point of view. Today, the electricity market is dominated by coal-fired plants and a growing but old fleet. The future energy mix is influenced by the availability of resources, political interventions, technical developments, and regional factors. He then focused on the pros and cons of various power plant technologies. There are many issues, which need to be solved, such as the rise in living standards, increasing needs of infrastructure, environmental regulations, life cycle extension of existing assets, and pushforward to clean technologies. The solution requires time and capital and can only be done with a well-coordinated global approach.

This presentation was followed by seven short lectures. The first from Mariska De Wild-Scholten (ECN) showed an environmental assessment of future photovoltaic technologies. She concluded that the analysis of the future requires a good knowledge of present-day technologies. Furthermore, it is necessary that the future assessment is based on economic issues, social acceptance, and today's environmental impacts. Jacques Richard (HES-SO) presented an LCA of a solar lawn mower. The results showed that the need of 15 kg Li-lo batteries is the most important issue, which is also the reason that the solar operating lawn mower exhibit higher impacts than gasoline and electric operating ones. It was concluded that more reliable inventory data on lithium ion batteries are required, which are currently revised by the ecoinvent Centre. The next presentation was held by Irene Steimen (oerlikon solar). She showed difficulties and problems companies face with regard to quantifying energy and mass flows when a factory is planned for a start-up technology. Examples are given for oversizing cables, transformers, and pipes. At the end of the presentation, three requests were given to the LCA community. Firstly, provide simple decision tools for engineers; secondly, do not spread LCAs with high uncertainties among society; and thirdly, maintain its excellent reputation. Matthew Chester (University of Leeds) then illustrated the use of LCA in long-term community energy planning with a 30-year time horizon. He raised some methodological questions such as how can LCA data be reliable and dynamic. Samuel Vionnet (EPFL) presented the Clean Sky project supported by various important industry partners. The aim of his work is to provide a tool engineers can use in the assessment of future aircraft technologies without being an expert in LCA. Silke Feifel (KIT) introduced a comparative LCA of lightweight boards consisting of thin cover layers, core layers made of paper, and frames versus chipboards. She concluded that lightweight board could reduce the demand for resources and GHG emissions in Germany. However, the potential increase in emissions occurring outside Germany was not quantified. In the last presentation of the day, Tobias Walser (ETH Zurich) showed a comparison of nano-silver versus conventional polyester T-shirts. The potential of nano-silver T-shirts lies in the lower washing frequency and temperatures. The results showed that only at breakthrough and exploitation of the full potential of nano-silver T-shirts their performance is better compared to conventional polyester T-shirts. However, the uncertainty is relatively high, nano-silver emissions are not considered in impact assessment methods and different nano-silver coating production technologies have different environmental impacts. Furthermore, it was mentioned that nano-silver may negatively affect the purification efficiency of sewage treatment plants and that the consumer behavior needs to be taken into account.

5 Discussion

Krewitt, Ott, and Hirschberg were asked to reflect the main conclusions of the NEEDS project. Together with the audience, it is concluded that a ranking of technologies on the basis of natural science only is not possible as this depends very much on the preferences of stakeholders and decision-makers. It is necessary that a preference order is established, which suits to most of the people. However, it will take years until the concept of external costs will be included in decision-making processes.

From the point of view of the participants of the NEEDS project, the potential in the instruments lies in the supporting of the decision-making process, which includes structuring the debate, sensibilizing decision-makers and stakeholders, and providing impulses to technology developers.

The general discussion was guided by Rolf Frischknecht (ESU-services Ltd.). The aim was to evaluate whether or not LCA is considered a useful method for future energy technology assessment and whether or not we know enough to establish such an LCA. He identified consensus in the following areas: (1) LCA of future technologies will provide a set of answers and not "the" answer; (2) today's technology performance does not help in assessing future technologies; (3) the environmental performance of present technologies must be known to be able to predict their future performance; (4) scenarios established by qualified experts about future technological and economic developments are indispensable in future technology assessments; and (5) the prediction of future technology developments depends on individual preferences and perceptions (e.g., level of optimism) and thus calls for harmonization.

The audience agreed that LCA is a suitable tool to support future technology assessments and that the scenario-based LCI databases developed within the NEEDS project (see http://www.needs-project.org) are of help for practitioners who deal with the environmental assessment of future situations.

The presentations of the discussion forum are available for download at http://www.lcainfo.ch/df/.

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