EPA/600/R-02/041
July 2002

Report on the International Workshop on Electricity Data for Life Cycle Inventories

Held at the Breidenbach Research Center, Cincinnati, Ohio, October 23-25, 2001

http://www.sylvatica.com/ElectricityWorkshop.htm

Summary by

Mary Ann Curran,
US Environmental Protection Agency
Cincinnati, Ohio, 45268

Margaret Mann
National Renewable Energy Laboratory
Golden, Colorado, 80401

Gregory Norris
Sylvatica, Inc.
North Berwick, Maine, 03906

Workshop Co-Hosted by

National Risk Management Research Laboratory
US Environmental Protection Agency
Cincinnati, Ohio, 45268
and
National Renewable Energy Laboratory
US Department of Energy
Golden, Colorado 80401

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio, 45268

Notice

The views expressed in these Proceedings are those of the individual authors and do not necessarily reflect the views and policies of the U.S. Environmental Protection Agency (EPA). Scientists in EPA's Office of Research and Development have prepared the EPA sections, and those sections have been reviewed in accordance with EPA's peer and administrative review policies and approved for presentation and publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

Abstract

A three-day workshop was held in October 2001 to discuss life cycle inventory data for electricity production. Electricity was selected as the topic for discussion since it features very prominently in the LCA results for most product life cycles, yet there is no consistency in how these data are calculated and presented. Approximately 40 people attended all or part of the meeting to discuss issues of data modeling and collection. Attendees included recognized experts in the electricity generation and life cycle assessment fields.

Five main topics of discussion were identified before the meeting began: 1) Modeling the response of the energy supply system to demand (i.e. marginal v. average data); 2) Defining the breadth and width of system boundaries to adequately capture environmental flows and data that are needed for impact modeling; 3) Allocating environmental burdens across co-products that come from the same process; 4) Modeling new and non-traditional technologies in which the data are highly uncertain; and 5) Including transmission and distribution in modeling of electricity generation. Breakout groups addressed the first four topic areas in individual discussion groups and reported the results in a plenary session on the last day of the workshop (it was decided during the meeting to include "transmission and distribution" in other discussions).

Several ideas were advanced by agreement in the break out groups' discussions, for example:

- The workgroup on marginal data made an important distinction in terminology by defining "marginal," "attributional," and "consequential" modeling; it further recommended that LCI databases be developed in such a way that they support *both* attributional and consequential modeling, and it cited the need for case studies of consequential modeling of the electricity system in order to shed light on many of the current questions surrounding this rather new and unfamiliar approach in LCI.

- The workgroup on boundaries created a first cut at listing environmental emissions that should be included in the inventory.

- The workgroup on new & non-traditional technologies noted that despite difficulties that arise in conducting LCAs on renewables, due to uncertain operating data, any database on electricity must be flexible enough to include different stressors.

- Access to unaggregated data was recognized as desirable by all the workgroups in order to meet most of the data needs.

A key success of the workshop was the creation of the larger network of LCA and electricity production experts that will provide a good foundation for continued discussions.

Contents

Exhibits

Chapter 1
Introduction

Data collection for life cycle inventories (LCIs) remains a critical factor in the successful completion of a life cycle assessment (LCA). Access to reliable data continues to be a significant barrier to the advancement and use of LCAs in environmental management.

Over the years, LCA practitioners have been left to their own means to collect and model inventory data as they have conducted studies for clients. However, these data are the property of the practitioner and not typically made available to the public, or they must be purchased. Furthermore, since different modeling assumptions can be made, there is no consistency in how these data are calculated and presented in different LCAs.

While most LCI data are specific to a particular study and its goal, there are data that are common in all LCIs, namely electricity, transportation and waste management. Electricity use, especially, features very prominently in the total LCA results for a majority of product life cycles. Therefore, the benefits of public LCI data on electricity generation would be high for those who undertake LCAs and for those who draw conclusions based on LCAs.

1.1 Background

Electricity is a major consideration in any LCA. It is important to accurately calculate and model resource use and pollutant releases for activities related to the generation and distribution of electricity, such as how and where electricity is produced, with what input requirements, and with what pollution and waste cones-quences. As LCAs are being conducted more frequently as part of overall environmental management approaches within both the public and private sectors, it is becoming increasingly important that LCI data become more readily-available. Also it is vital that data be used consistently between LCAs in order to lead to more fairly comparable results and reliable conclusions.

Modeling of the environmental burdens of electricity production is far from a simple or straightforward task. Indeed, the electricity supply system is among the most complex of all the industries addressed in an LCA. This complexity arises from a number of factors, including:

- the broad geographic scope of power grids and electricity markets with power wheeling;
- the dynamics of supply dispatch in response to demand changes, overlaid on daily and seasonal dynamics;
- the wide variation among generation stations in emissions and inputs per unit generation across and even within fuel types;
- the rapid ongoing evolution and regional variety of the electricity system and the regulatory environment in which it operates;
- the rapid and ongoing evolution of electricity generation technologies, and uncertainties about future market penetration of new technologies, and
- the potentially long time frames and importance of electricity consump-tion for the life cycles of durable products.

Existing LCI datasets generally fail to capture the effects of these complexities. Of course, all models must be simplifications of reality to be useful, but the potential effects of these complexities upon the usefulness of LCI results from current databases warrants examination. Another priority issue for resolution is the lack of consistency in scope (both of environmental flows and technospheric flows) among existing databases for different regions, and even among alternative databases covering the same region.

In order to comprehensively address the issues involved in modeling data for electricity generation, it was decided to hold a 3-day workshop with recognized experts in the electricity generation and life cycle assessment fields to work together to lead to agreement that could be used in developing a uniform/consistent electricity database for life cycle inventories.

1.2 Workshop Attendees

Approximately 40 people attended all or part of the meeting. The list of attendees is located in the Appendix. The breakdown of representation is approximately as follows:

Industry Experts*	10%
Government Experts*	15%
LCA Practitioners	20%
LCA Researchers	20%
Academia	17.5%
Other US EPA'ers	17.5%

* Experts in traditional & non-traditional electricity generation.

1.3 Identifying the Issues

The following topical areas, referred to as the "issues," were identified by the workshop planners and used to organize the presentations and discussions:

- *Marginal v. Average: "Should LCA model the response of the energy supply system to demand?" (and consequences for co-product allocation)*
- *Boundaries: "How wide and broad should the boundaries be to capture environmental flows and data that are needed for impact?"*
- *New & Non-Traditional: " How should LCA model new technologies, in which the data are highly uncertain, and how should increased demand for new technologies be accounted for?"*
- *Co-Product Allocation: "How should environmental burdens be allocated across co-products that come from the same process?"*
- *Transmission/Distribution: "How should T&D impacts be included in modeling of electricity generation?"*

Prior to the workshop, a short summary document, entitled "*An International Workshop on Electricity Data for Life Cycle Inventories: Introduction and Overview (August 2001)*," was prepared to describe these issues and what they mean. To help initiate the thought process and stimulate responses from the invitees to the meeting, a series of 25 questions was also posed in the summary document.

Input on these issues was solicited from everyone who planned to attend the workshop as well as those who were interested in the effort but were unable to attend. Around ten thoughtpieces and other background material, such as journal articles, were submitted. A summary document was prepared from these submittals and distributed to everyone before the workshop ("International Workshop on Electricity Data for Life Cycle Inventories: Summary of Feedback on Issues," 18 October 2001) as well as posted on the website that was created expressly for the workshop **http://www.sylvatica.com/** ElectricityWorkshop.htm.

The first day of the workshop began with an initial plenary session in which presentations were made on data sources and a summary of each issue area. This led to breakout working groups that were tasked on the second day of the workshop with discussing the issues and identifying where there was either consensus or disagreement.

Workgroup Members

Marginal versus Average Data:
John Abraham, US EPA
John Burckle, US EPA (retired), USA
Tomas Ekvall, Chalmers, Sweden
Bill Franklin, Franklin Associates, USA
Patrick Hofstetter, ORISE Post Doc, Switzerland
Greg Keoleian, University of Michigan, USA
Benoit Maurice, EDF, France
Greg Norris, Sylvatica, USA
Philippa Notten, University of Capetown, S. Africa
Scott Properzi, Energi D2, Denmark
John Sheehan, NREL, USA
Tom Tramm, Consultant, USA
Bo Weidema, 2.0 LCA Consultants, Denmark

New and Non-Traditional (NNT) Technologies:
Merwin Brown, NREL, USA
Joyce Cooper, University of Washington, USA
Rolf Frischknecht, ESU Services, Switzerland
Douglas Gyorke, NETL, USA
Marty Heller, University of Michigan, USA
Wolfram Krewitt, ITT, Germany
Ivars Licis, US EPA
Lynn Manfredo, SAIC, USA
Maggie Mann, NREL, USA
Jonathan Overly, University of Tennessee, USA

Boundaries & Co-Product Allocation:
Jane Bare, US EPA
Bill Barrett, NRC Post Doc, USA
Jamie Meil, Athena Institute, USA
Michael Overcash, North Carolina State University, USA
Bev Sauer, Franklin Associates, USA
Rita Schenck, IERE, USA
Caroline Setterwall, Vattenfall, Sweden
Tim Skone, SAIC, USA
Ray Smith, US EPA

Chapter 2
Summaries of the Discussions on the Issue Areas

Summaries of the discussions on Marginal versus Average, Boundaries, Co-Product Allocation, and New & Non-Traditional were presented to the group in plenary. The originally-planned discussion on T&D was folded into the discussions under both Boundaries and New & Non-Traditional. The sections below describe the workgroup sessions.

2.1 Deliberations and Conclusions from the Breakout Group on Marginal versus Average Modeling

The group began by clarifying its objectives. They were identified as follows:

- Clarify terminology, define the meanings of key terms.
- Determine when attributional and consequential LCI are each appropriate.
- Characterize the feasibility of attributional and of consequential LCI as applied to electricity supply, in terms of:
  - Cost and time.
  - Data availability, quality, and uncertainty.
- Address the issue of clarifying how the consequential approach might be applied in practice, with what models and data.

A fifth objective had initially been identified for the group, but was never engaged by the group as being particularly interesting, important, or clear:

- Determine whether there are different or equivalent answers to the above four issues, depending on whether one is addressing either of the following two application areas:
  - Electricity LCI data for use in other, general LCIs.
  - Using LCI to compare electricity generation options.

Terminology

In defining and clarifying terminology, we built on the contributions of Tomas Ekvall.

Decisions mean initial disturbances or changes to some part of the LCI system. Examples of decisions include whether to locate a new factory in a given region, or whether to install a high-efficiency device rather than a standard-efficiency device, or whether to pass more stringent building codes or appliance efficiency standards.

Decisions lead to *Consequences,* through whole series or chains of cause-effect relationships. Other synonyms for consequences include effects and outcomes. Example consequences of interest here would include emissions from electricity generation, and investments in particular new kinds of power generating capacity.

Both decisions and consequences can have the properties of timing, duration, and magnitude. It is magnitude which leads to the definition of "marginal."

Marginal disturbances or perturbations are infinitesimal disturbances; e.g., installing one new end-use is a small but not an infinitesimal disturbance. A marginal disturbance is in theory infinitesimal, but in practice it is small enough to be approximated as an infinitesimal disturbance. This requires that the response to the disturbance be proportional to the magnitude of the disturbance.

Marginal consequences are the response of the system to a marginal disturbance. For example, the marginal consequences of a very small increase in electricity demand may include slight increase in air pollutant emissions and fuel consumption.

The workgroup's discussion moved from using the term *"marginal versus average"* to *"consequential versus attributional."* Prior authors have used terminology to differentiate "marginal versus average" LCI, and they have also labeled the options as "retrospective versus prospective" LCI. The breakout group determined that the central distinction being considered by this breakout group was one best described as differentiating "attributional" versus "consequential" LCI. Attributional and consequential LCIs are modeling methods which respond to different questions:

- Attributional LCIs attempt to answer "how are things (pollutants, resources, and exchanges among processes) flowing within the chosen temporal window?" while
- Consequential LCIs attempt to answer "how will flows change in response to decisions?"

Finally the group noted that *retrospective* LCIs are LCIs about prior situations or changes/decisions which occurred in the past, while *prospective* LCIs are about future situations or changes/decisions. An LCI can therefore be prospective attributional (how will things be flowing in the future?), prospective consequential (how will a future decision change flows?), retrospective attributional (how were things flowing in the past?) and retrospective consequential (how did a prior decision change the flows?).

When are attributional and consequential LCI each appropriate?

The <u>attributional approach</u> to LCI serves to allocate or attribute, to each product being produced in the economy at a given point in time, portions of the total pollution (and resource consumption flows) occurring from the economy as it is at a given point in time. Thus, annual electricity production from hydropower in the Pacific Northwest would be assigned or attributed to each of the uses of kWh of electricity occurring in the Pacific Northwest during that same year.

The rules used to define which processes are in or out of the system in attributional modeling are those based on an observation of how materials and energy are flowing in the system at the given point in time. For example, if concrete is made with 1 kg fly ash and 1 kg Portland Cement per unit of concrete output, then the LCI model will show these flows into and out of the concrete manufacturing process.

Note that the "given point in time" could be past, present, or future.

The <u>consequential approach</u> to LCI attempts to estimate how flows to and from the environment will *change* as a result of different potential decisions. In general, the system response to changes in output demand (e.g., increased or decreased demand for some product) will vary between the short- and long-term. In the short term, the response will be changes in output from existing production capacity (e.g., existing power plants, factories, etc.) In the long term, the response will be changes in the timing, and perhaps the nature, of investments in new production capacity.

The rules used to define which processes are in or out of the system in consequential modeling are those based on an estimation of how material and energy flows will change as a result of the potential decisions or disturbances. In the fly ash example, if the output of fly ash is constrained – namely, if it is fixed based on the demand for electricity – then increases in the demand for high-fly-ash-concrete will not change the output of fly ash in the short run. Instead, it would increase the output of concrete made 100% from Portland Cement. The consequential LCI model would attempt to take such output constraints explicitly into account.

Characterizing the Response of the Electric Utility System to Demand Changes

Some members of the breakout group were familiar with realities of how the electricity system (at least in the US) currently responds to changes in demand. Others were familiar with responses of electricity systems in Europe. From their input, the following general facts were captured:

1) When the results over a year are aggregated, the short-term output responses to electricity demand changes typically occur at plants that have the highest variable cost among those operating at the time of the demand change.[1]

2) In the long term, the type of new capacity added is generally the one which is estimated (by investment decision makers) to satisfy the given load shape at the lowest overall cost.

3) The future is irreducibly uncertain, while the electricity supply system is dynamic and evolving. Thus, there are important levels of irreducible uncertainty concerning how the electricity supply system will respond to demand changes, even if we used the most sophisticated models available.

[1] Note that on an hourly basis there are exceptions. For example, hydropower is often dispatched to meet daily peaks rather than base load. Hydro units respond more reliably than more complex generating options, so they are scheduled to come on to meet the daily peaks or to address local environmental concerns. However, limited water supply means that there are only so many kilowatt-hours available per year from a hydro unit, so by the end of the year, demand changes accruing during the year will not have affected the output from the hydro unit.

In addition, it is noted that in contrast with many other products, electricity has the specific characteristic that it cannot be stocked directly. At any moment, production must be equal the sum of consumption and transmissions losses. Throughout the day, the load shape varies greatly due to increasing and decreasing use, such as lighting at night. To produce electricity, utilities typically have different power plants which are able to adapt their production to the consumption, producing electricity as base load, (e.g., nuclear energy), semi-base-load (e.g., coal, gas, fuel power plant) and peak load (e.g., gas turbine). This element has to be taken into account when one tried to characterize the response of the electric utility system to demand changes. A "base load use" or a "peak load use" will not have the same answer. Rather than using simple assumptions to characterize electricity production, LCA practitioners should model for electricity planning which allows for the integration of such parameters.

Appropriateness and Feasibility of Each Method

The participants agreed that, "ideally," LCA results would inform decision makers about the consequences of decision options that they are evaluating. However, there remained a significant level of concern about switching from attributional to consequential LCI modeling. Perhaps this is because the participants had not, with only two exceptions, ever undertaken or read the results of a consequential LCA.

Group participants had the following questions about consequential LCI:

- Does the change from attributional to consequential LCA ("A→ C") affect the results of the LCI? How much? In what cases, i.e., which product types, in which geographic regions?
- Does A→ C alter LCA-based decisions?

- How easy will consequential LCA results be to explain to users of the results?
- How easy will consequential LCA be to perform?

Recommendations
Based on its deliberations and concerns, the breakout group concluded with the following recommendations:

1) LCI databases should be developed in a way that is *technology-based*, so that the data can support either attributional or consequential modeling. Specifically, they should:

   a) not aggregate over different technology types within a sector and
   b) not aggregate over markets.

This will require solving issues around the protection of confidential information, such as is already faced by developers of transparent LCI databases.

2) LCI databases should contain ample meta-data, so that users can make informed modeling decisions to use the data for either attributional or consequential modeling.

3) Feasibility studies which apply energy system models are needed in order to generate short-, medium- and long-term LCI results for a modest incremental change in demand for different regions, and for different types of end-use, which are characterized by differences in timing (daily and seasonal) and duration. Such studies would provide answers to all four of the questions posed by group participants about currently unknown aspects of consequential modeling of the electricity supply system.

2.2 Deliberations and Conclusions from the Breakout Group on Boundaries and Flows

LCA attempts to approximate the comprehensive treatment of the environmental, health and resource burdens associated with product systems. In theory, this comprehensiveness entails inclusion of "all significant" burdens (e.g., pollution releases, resource consumption flows, or other impacts) from "all" causally-connected processes. Thus, the system boundary for a life cycle inventory model requires a series of choices along two dimensions: environment and supply chain. The purpose of the Boundary and Flows Workgroup (WG) was to discuss the following topics related to assembly and handling of electricity LCI data:

1. Which activities and operations along the supply chain should be included? That is, how wide and how broad should the system boundaries be drawn? (e.g., should capital equipment be included? transport of workers to the production sites? service sector inputs such as from designers, lawyers, accountants, advertising, etc.?)
2. Based on prior LCA and non-LCA environmental evalua-tions of the electricity supply system, is there a set of environmental flows for which reporting in LCI databases should be required? Is it possible to define a recommended set of environmental flows that would be sufficient to include in databases?
3. What is the most commonly accepted system of nomen-clature for environmental flows?

The workgroup successfully addressed the first two questions/topics, however, the scope of the third question was determined to be too broad and extensive to be covered within the limited meeting time of the WG.

Boundaries

The participants evaluated which activities and operations along the supply chain/life-cycle should be included for energy supply systems. Particularly, they discussed what should be included (e.g., should capital equipment be included? transportation of workers to the production sites? service sector inputs such as from designers, lawyers, accountants, advertising, etc.?). The consensus was to include infrastructure only for dedicated resources. For example, the material used to construct a boiler used in a coal-fired utility plant should be included, but the materials used to construct the cranes that are used to erect boilers and other plant structures would not be included. Likewise, impacts from workers traveling to and from work should be excluded. This is not a hard-and-fast rule, but more a general rule-of-thumb to be used in drawing boundaries for energy supply systems. The potential impact from infrastructure operations should always be evaluated, even on a cursory level, to support the exclusion with confidence.

Taking a step back, the workgroup also evaluated the main processes or activities that should be considered when conducting an LCI of any energy supply system. The results of this effort are illustrated in Exhibit 1. Process or activities identified in Exhibit 1 for energy supply systems should not be excluded without proper process knowledge. If excluded, the corresponding rationale should be documented in a transparent manner and provided with the results of the LCI. The specific nomenclature for each process or activity identified in Exhibit 1 may vary from one practitioner to another, but the intent of each box should be evaluated for each LCI.

Environmental Flows

The Boundaries and Flows workgroup evaluated the feasibility of a "default" or "standard" list of environmental flows for electricity supply systems. The consensus of the workgroup and the Workshop attendees was that a "default" list would provide the perception that only those environmental flows were of significant concern and all others could be excluded. This is not true. Our ability (as LCA practitioners) to understand the impacts from energy supply systems is based on previous experience (past LCA work) and to a greater extent, the availability of data to model the energy supply system. Future efforts to model the energy supply system should not be limited to previous experiences or perceived understandings of significant environmental flows; rather, every effort should be made to challenge the validity and accuracy of scientific knowledge upon which the conclusions about energy supply systems are drawn.

Therefore, the workgroup rephrased the question to ask "is there a minimum list of environmental flows for energy supply systems that one should expect to be included in an LCI?" With some apprehension, the workgroup developed a tentative minimum list of environmental flows to be considered for energy systems; see Exhibit 2. Exclusion of these environmental flows should raise concern towards the comprehensiveness of the LCI data set.

Exhibit 1. System Boundary for Energy Supply Systems

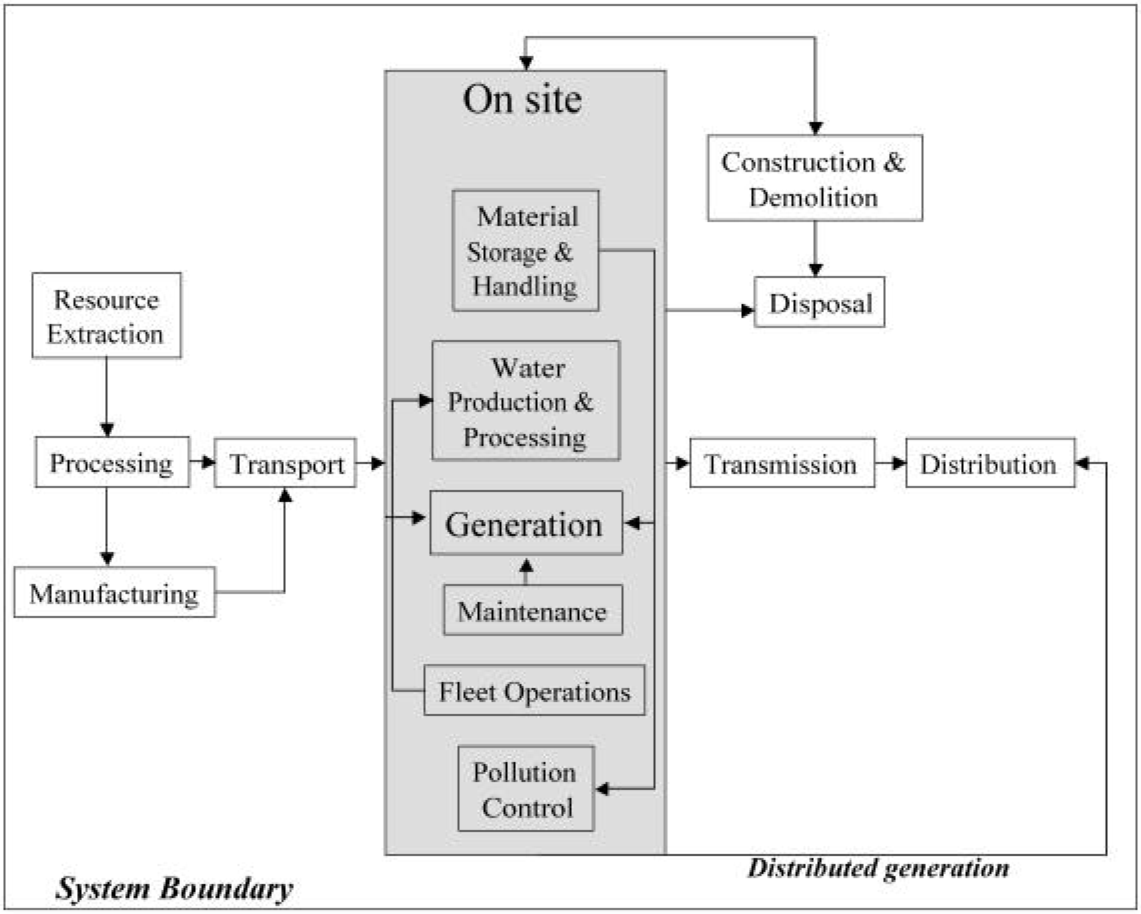


Exhibit 2. "Minimum" List of Environmental Flows for Energy Supply Systems

Resources	***Air Emission***	***Water Emissions***
Water (location & type)	CO_2	Chemical oxygen demand (COD)*
Fuel (in ground)	CO	TDS
Minerals (in ground)	PM (10, 2.5)	Total suspended solids (TSS)
Biomass (harvested)	CH_4	Biological oxygen demand (BOD) (5, 7, 10)*
Land use (area & location)	SO_X	Flow
	NO_X	Temperature change,** or thermal loading in energy units
Wastes	NH_3	NH_3 (as N)
Solid waste	Hg, Pb	Total Kjeldahl nitrogen (TKN) (as N)
Radioactive Waste (H, M, L)	VOC (NM)	NO_3, NO_2 (as N)
Hazardous Waste	Dioxin	Polycyclic aromatic hydrocarbons (PAH's)
	PAHs	Phosphates (as P)
Other Releases	SF6	Cu, Ni, As, Cd, Cr, Pb, Hg
radionuclides	HFCs	

* COD and BOD are indicators of water quality rather than flows

** Limitation on temperature depends on the temperature of the river

Next Steps for Boundaries and Flows Research

The workgroup identified the following next steps to continue the progress made during the electricity workshop.

1. Apply the system boundaries and environmental flows guidance in the development of the following model energy supply systems:
    a. Coal w/anthracite
    b. Coal w/lignite
    c. Natural Gas
    d. Oil
    e. Nuclear
    f. Hydro
    g. Wind
    h. Biomass
    i. Geothermal
    j. Other
2. Research the potential impact from the following, and other, non-traditional environmental flows:
    a. Noise
    b. Radiation
    c. Biological Resources

2.3 Deliberations and Conclusions from the Breakout Group on Co-Product Allocation

Co-product allocation arises as an issue whenever a process produces more than one useful product. For example, steam turbine systems may sell both electricity and low pressure steam as useful products. When co-products are present, practitioners must determine how much of the burdens associated with operating and supplying the multi-output process should be allocated to each co-product. Practitioners must also decide how to allocate environmental burdens across co-products when one is a waste stream that can be sold for other uses.

The ISO standards for LCA, particularly ISO 14041 on inventory analysis, provide methodological guidance on this issue. But they call for practitioners to attempt to avoid allocation if possible; and secondly, to attempt modeling approaches which reflect the physical relationships between the process outputs and its inputs. In summary, proper application of the ISO guidelines on allocation requires a physical understanding of the co-product production processes. The consensus of the workgroup was to follow the guidance outlined in ISO 14041 for energy supply systems. The following highlights some key issues related to allocation per ISO 14041.

ISO 14041 requires the following procedure be used for allocation in multifunction processes:

- Allocation should be avoided, wherever possible, either through division of the multifunction process into sub-processes, and collection of separate data for each sub-process, or through expansion of the systems investigated until the same functions are delivered by all systems compared.
- Where allocation cannot be avoided, the allocation should reflect the physical relationships between the environmental burdens and the functions, i.e., how the burdens are changed by quantitative changes in the functions delivered by the system.
- Where such physical causal relationships alone cannot be used as the basis for allocation, the allocation should reflect other relationships between the environmental burdens and the functions.

For allocation in open-loop recycling, ISO 14041 recommends the same procedure but allows a few additional options. If the recycling does not cause a change in the inherent properties of the material, the allocation may be avoided through calculating the environmental burdens as if the material was recycled back into the same product. Otherwise, the allocation can be based on physical properties, economic value, or the number of subsequent uses of the recycled material. The international standard does not include information on the effect of the different methods on the life cycle modeling, for example the feasibility of the methods, the amount of work required, or what type of information that results from the application of the methods.

A major point which came to light during the workshop discussions on allocation was that the choice of allocation method depends considerably upon whether the LCA is being performed from an attributional or a consequential point of view. This point is demonstrated in the dissertation and publications of Tomas Ekvall. See, for example, his 1997 paper with Ann-Marie Tillman, published in the *International Journal of LCA*.[1] In that paper, they very helpfully differentiate cause-oriented from effects-oriented bases for allocation, and suggest that for LCAs supporting decisions about the future (e.g., for consequential LCAs), effects-oriented basis for allocation is appropriate. System expansion is an effect-oriented approach, while economic allocation is a cause-oriented approach.

This issue of the relationship between consequential/attributional LCA and the choice of allocation method is also discussed together with a detailed presentation of system expansion methods for allocation in a 2001 paper by Bo Weidema in the *Journal of Industrial Ecology*.[2]

2.4 Deliberations and Conclusions from the Breakout Group on New & Non-Traditional Technologies (NNT)

In working on the question of how to conduct LCAs of NNT technologies for electricity generation, the group felt it necessary for the purpose of this discussion, to distinguish their role as database developers and not LCA practitioners.

The goal of the database effort was determined to be three-fold: 1) provide good inventory data for each NNT generation technology, 2) provide guidelines and/or models that will help practitioners choose the correct electricity mix, and subsequent environmental stressors, for their product life cycle assessment, and 3) ensure consistency.

Scope of NNT generation

Areas of interest for NNT generation include:

- Future technologies
- Renewables
- Non-baseload generators
- Distributed generation

Future technologies include those that have the potential to someday contribute significantly to the grid mix, but do not currently influence the environmental impact of common electricity usage. For these technologies, there is limited operating data, which is almost never site-specific. While actual operating conditions are difficult to predict with certainty, these technologies are often viewed as being more environmental benign. Future technologies may include the second category, renewables, but will also include generation options such as fuel cells, microturbines, and advanced coal.

Difficulties that arise in conducting LCAs on renewables present challenges for LCI database developers. For example, in LCI's that are based on a functional unit of producing a KWh, operating emissions may be very low or essentially zero. The predominant source of emissions associated with the generating technology may be construction emissions, which are problematic to allocate over the functional unit of KWh.

Additionally, because some impacts can be very different than those from traditional generators (e.g., bird kills), the database must be flexible enough to include different stressors. Finally, an important driver for renewables is the avoidance of conventional generation and impacts. Future discussions on database development will need to agree on how avoided impacts are handled.

Non-baseload generators are those that do not produce power on a continuous or controllable basis. Examples include some renewable generators such as wind and photovoltaics (PV), or power plants that are used for providing peak energy. With regard to database development, care must be taken in data sets when referencing stressors to a functional unit. The functional unit can be defined either from the supply-side as the kWhs that come from the generator itself, or from the demand-side as the kWhs that are consumed by the user of the electricity.

The drivers for distributed generation are the demand for reliable power, the desire to avoid down-time costs, and the mitigation of significant up-front capital expenditures for large generators and transmission and distribution infrastructure. Distributed generators (DGs) are typically small, and may use fossil or renewable fuels. For a large penetration into the grid, LCA practitioners may take account, during impact assessment, of the fact that emission source locations are distributed over a large geographic region as well. Additionally, depending on the reason for a DG installation, the functional unit may not be kWh.

Focus of the discussion

In the course of the discussion on NNT generation, four questions were answered:

- How are data sets constructed for new technologies, for which there are higher degrees of uncertainty in environmental stressors?
- Is there a need to develop a common future energy scenario that considers renewable and distributed energy sources for use in prospective LCAs?
- How should distributed generation be accounted for in national or regional energy grid data?
- What percent of the grid mix does a technology have to supply before we care about it in our product LCAs?

For the entire database, the group felt very strongly that all data should be kept as unaggregated as possible. That is, each set of data should not represent the cradle-to-gate inventory for the technology it is describing. Rather, construction, mining, transportation, and operation should be provided in data modules such that a user can separate them out.

Results of the discussion

The questions posed above were answered as follows:

1. **How are data sets constructed for new technologies, for which there are higher degrees of uncertainty in environmental stressors?**
   - Use best available mass & energy & production data.
   - Where there are data gaps, make a conservative expert judgment for missing data points and document assumptions (SETAC working group)
   - Include a calculation routine that allows the users to vary performance/emissions parameters.
   - Document assumptions, sources of data, and year in which data were obtained.
   - Be alert to the situation where you need to input stressors that are not common to current generation technologies (e.g., bird kill, land use).

2. **Is there a need to develop a common future energy scenario that considers renewable and distributed energy sources for use in prospective LCAs?**
   - No. However, there is a need to provide for the application of various future energy scenarios.
   - Provide a tool or modules that describe different energy mixes/scenarios.

3. **How should distributed generation be accounted for in national or regional energy grid data?**
   - The same way that traditional generators are accounted for.
   - Different transmission and distribution losses are important.
   - Stressors from non-baseload generation should be discounted to the percent of time that they supply electricity to the consumer.

4. **What percent of the grid mix does a technology have to supply before**

we care about it in our product LCAs?

- If you can assemble life cycle inventory data for a technology, provide it in the database.
- Use the module/tool described in 2) to give the user an opportunity to incorporate them into their grid mix, or they can do it manually.

In addition to the issues described above, other concerns should be considered in future related activities. Of key importance is the incorrectness of using current data for future technologies. Conclusions regarding the environmental benefits that could be achieved with future technologies would be misguided when significant technological advancement is possible. Similarly, while the database is to contain inventory data for the various technologies, LCAs conducted for different timeframes will need to take into account predictions of different grid mixes.

Chapter 3
Conclusions

The workshop successfully met its stated goal to facilitate the exchange of ideas and information. As was identified in the issues paper and follow-up discussions, the information needs to be established are too numerous to be fully explored or resolved at a brief three-day workshop. However, the hard work of the break out groups lead to many of the discussions points being advanced.

- The workgroup on marginal data made an important distinction in terminology by defining "marginal," "attributional," and "consequential." While there was much discussion and many questions remained unresolved, the group did achieve consensus on the following recommendations:

    - LCI databases should be developed in such a way that they support *both* attributional and consequential modeling.
    - There is the strong need for case studies of consequential modeling of the electricity system in order to shed light on many of the current questions surrounding this rather new and unfamiliar approach in LCI.

- The workgroup on Boundaries created a first cut at a "minimum list" of environmental emissions that should be included in the inventory.

- The workgroup on New & Non-Traditional Technologies noted that despite difficulties that arise in conducting LCAs on renewable generating technologies, due to uncertain operating data, any database on electricity must be flexible enough to include non-traditional stressors (e.g., bird kills).

A consistent thread throughout all the conversations was the desire for having access to unaggregated data, although the practicalities involved in this, such as confidentiality issues, were not discussed.

A key success of the workshop was the network that was created among experts in the LCA and electricity production fields. The establishment of this larger workgroup will provide a good foundation for continued discussions.

The workshop conveners are exploring next steps, and encourage all workshop participants as well as other interested parties to please use the workshop website as a repository for documents, thought pieces, and links which relate directly to the topics discussed at the workshop and summarized in this document.

References

[1] Ekvall T, and Tillman A-M, "Open-Loop Recycling: Criteria for Allocation Procedures," Int Journal of LCA , 2(3), pp155-162, 1997.

[2] Weidema B., "Avoiding Co-Product Allocation in Life-Cycle Assessment," Journal of Industrial Ecology, 4(3), pp11-33, 2001.

Electricity Data for Life Cycle Inventories

A.W. Breidenbach Research Center
26 W. Martin Luther King Drive
Cincinnati, Ohio, USA 45268
October 23 – 25, 2001

Agenda

Tuesday, October 23rd

9:00 - 9:30 Registration (there is no fee to attend this workshop)

9:30 - 12:00 Plenary 1 (Auditorium) Opening Remarks

9:30 - 10:00 *Welcome and Objective of the Workshop, with Basics of LCA Practice*
Mary Ann Curran, LCA Researcher, US EPA/ORD
10:00 – 10:30 *Uses and Users of Electricity LCA Information*
Bo Weidema (invited)
10:30 – 11:45 *Electricity Data Sources*
Asia – A. Inaba, NIAIST
Europe – W. Krewitt, DLR-ITT
Southern Countries – A. Quiros (invited), EcoGlobal
US – R. Morgan, US EPA
11:45 - 12:00 *Plan for Conducting the Workshop*

12:00 – 13:00 Lunch (on your own)

13:00 – 15:00 Plenary 2 (Auditorium) Presentation and Discussion of Issues

13:00 - 13:45 *Boundaries:*
"How wide and broad should the boundaries be to capture environmental flows and data that are needed for impact?"
Gregory Norris, Sylvatica and Patrick Hofstetter, ORISE
13:45 - 14:30 *Marginal v. Average:*
"Should LCA model the energy supply system's response to demand?" (and consequences for co-product allocation)
Tomas Ekvall, Chalmers

14:30 - 15:00 *New & Non-Traditional:*
" How should LCA model new technologies, in which the data are highly uncertain, and how should increased demand for new technologies be accounted for?"

Margaret Mann, National Renewable Energy Laboratory, DOE

15:00 Introduction of Discussion Groups and Room Assignments

18:00 Dinner with Discussion Groups

Wednesday, October 24

8:00 - 12:00 Resume Discussion Group Meetings:
Parallel groups on the following topics:
Boundaries; New & Non-Traditional, and Marginal v. Average

12:00 - 13:00 Lunch (on your own)

13:00 – 17:00 Making Progress with the Discussions

13:00 - 14:00 Preliminary Report Outs (20 minutes each)
14:00 – 17:00 Continue Original Discussion Groups
Introduction of 2 New Parallel Groups:
Co-Product Allocation & Transmission/Distribution

18:00 Dinner

Thursday, October 25

8:00 – 13:30 Plenary 3 (Auditorium) Presentation of Discussion Summaries

8:00 – 9:00 Boundaries
9:00 – 10:00 New & Non-Traditional

10:00 – 10:15 Coffee Break

10:15 – 11:15 Marginal v. Average
11:15 – 11:45 Allocation
11:45 – 12:15 Transmission and Distribution

12:30 - 13:30 Brown-bag Lunch and Final Discussion, Plans, Next Steps

13:30 Adjourn

International Workshop on Electricity Data for Life Cycle Inventories

FINAL LIST OF ATTENDEES
October 23-25, 2001
Cincinnati, Ohio, USA

John P. Abraham **Phone:** 513-569-7124 **Fax:** 513-569-7111 **E-mail:** abraham.john@epa.gov	**US EPA, National Risk Management Research Laboratory** 26 W. Martin Luther King Drive, MS-466 Cincinnati, OH 45268 USA
Jane Bare **Phone:** 513-569-7513 **Fax:** 513-569-7111 **E-mail:** bare.jane@epa.gov	**US EPA, National Risk Management Research Laboratory** 26 W. Martin Luther King Drive, MS-466 Cincinnati, OH 45268 USA
Bill Barrett **Phone:** 513-569-7220 **Fax:** 513-569-7471 **E-mail:** barrett.william@epa.gov	**US EPA, National Risk Management Research Laboratory** 26 W. Martin Luther King Drive Cincinnati, OH 45268 USA
Merwin Brown **Phone:** 303-275-4364 **Fax:** 303-275-3059 **E-mail:** merwin_brown@nrel.gov	**National Renewable Energy Laboratory** 1617 Cole Blvd. Golden, CO 80401 USA
John Burckle **Phone:** 513-569-7496 **Fax:** 513-569-7471 **E-mail:** burckle.john@epa.gov	**US EPA, National Risk Management Research Laboratory** 26 W. Martin Luther King Drive Cincinnati, OH 45268 USA
Joyce Cooper **Phone:** 206-543-5040 **Fax:** 206-685-8047 **E-mail:** cooperjs@u.washington.edu	**University of Washington** Seattle, WA 98195 Box 352600 USA
Mary Ann Curran **Phone:** 513-569-7782 **Fax:** 513-569-7111 **E-mail:** curran.maryann@epa.gov	**US EPA, National Risk Management Research Laboratory** 26 W. Martin Luther King Drive, MS-466 Cincinnati, OH 45268 USA
Tomas Ekvall, Ph.D. **Phone:** +46-31-772 14 45 **Fax:** +46-31-772 35 92 **E-mail:** tomas.ekvall@entek.chalmers.se	**Chalmers University of Technology** Energy Systems Technology Group Sweden
Gordon Evans **Phone:** 513-569-7684 **Fax:** 513-569-7111 **E-mail:** evans.gordon@epa.gov	**US EPA, National Risk Management Research Laboratory** 26 W. Martin Luther King Drive, MS-466 Cincinnati, OH 45268 USA
William E. Franklin **Phone:** 913-649-2225 Ext. 232 **Fax:** 913-649-64944121 **E-mail:** wfranklin@fal.com	**Franklin Associates, Ltd.** West 83rd Street, Suite 108 Prairie Village, KS 66208 USA
Rolf Frischknecht **Phone:** +41 1 940 61 91 **Fax:** +41 1 940 61 94 **E-mail:** frischknecht@esu-services.ch	**ESU-Services** Kanzleistrasse 4 Switzerland
Douglas Grosse **Phone:** 513-569-7844 **Fax:** 513-569-7585 **E-mail:** grosse.douglas@epa.gov	**US EPA, National Risk Management Research Laboratory** 26 W. Martin Luther King Drive Cincinnati, OH 45268 USA

Douglas F. Gyorke
Phone: 412-386-6173
Fax: 412-386-4775
E-mail: douglas.gyorke@netl.doe.gov

USDOE / National Energy Technology Laboratory
P.O. Box 10940
Pittsburgh, PA 15236
USA

Paul Harten
Phone: 513-569-7045
Fax: 513-569-7471
E-mail: harten.paul@epa.gov

US EPA, National Risk Management Research Laboratory
26 W. Martin Luther King Drive
Cincinnati, OH 45268
USA

Martin Heller
Phone: 734-764-2637
Fax: 734-647-5841
E-mail: mcheller@umich.edu

Center for Sustainable Systems / University of Michigan
430 East University
Ann Arbor, MI 48109-1115
USA

Abby Hill
Phone: 513-569-7100
Fax: 513-569-7585
E-mail: hill.abby@epa.gov

US EPA, National Risk Management Research Laboratory
26 W. Martin Luther King Drive
Cincinnati, OH 45268
USA

Patrick Hofstetter
Phone: 513-569-7326
Fax: 513-569-7111
E-mail: hofstetter.patrick@epa.gov

ORISE Research Fellow at the US EPA
26 W. Martin Luther King Drive, MS-466
Cincinnati, OH 45268
USA

George Huffman
Phone: 513-569-7431
Fax: 513-569-7471
E-mail: huffman.george@epa.gov

US EPA, National Risk Management Research Laboratory
26 W. Martin Luther King Drive
Cincinnati, OH 45268
USA

Gregory A. Keoleian
Phone: 734-764-3194
Fax: 734-647-5841430
E-mail: gregak@umich.edu

Center for Sustainable Systems / University of Michigan
East University, Dana Building
Ann Arbor, MI 48109-1115
USA

Dr. Wolfram Krewitt
Phone: +49-711-6862766
Fax: +49-711-6862783
E-mail: wolfram.krewitt@dlr.de

German Aerospace Center (DLR), Inst. of Tech. Thermodynamics
System Analysis and Technology Assessment
Pfaffenwaldring 38-40
Germany

C.C. Lee
Phone: 513-569-7520
Fax: 513-569-7471
E-mail: lee.chung@epa.gov

US EPA, National Risk Management Research Laboratory
26 W. Martin Luther King Drive
Cincinnati, OH 45268
USA

Ivars Licis
Phone: 513-569-7718
Fax: 513-569-7471
E-mail: licis.ivars@epa.gov

US EPA, National Risk Management Research Laboratory
26 W. Martin Luther King Drive
Cincinnati, OH 45268
USA

Lynn Manfredo
Phone: 412-386-6839
Fax: 412-386-4516
E-mail: manfredo@netl.doe.gov

SAIC
P.O. Box 18689
Pittsburgh, PA 15236
USA

Margaret Mann
Phone: 303-275-2921
Fax: 303-275-2905
E-mail: margaret_mann@nrel.gov

National Renewable Energy Laboratory
1617 Cole Blvd., MS-1613
Arvada, CO 80401
USA

Benoit Maurice
Phone: 33 1 60 73 74 38
Fax: 33 1 60 73 75 27
E-mail: Benoit.Maurice@edf.fr

Electricite de France - R&D Division
Site des Ranardieres. Route de Sens - Ecuelles
France

Jamie Meil
Phone: 613-722-8075
Fax: 613-722-962828
E-mail: jkmeil@fox.nstn.ca

Athena Sustainable Materials Institute
St. John Street, P.O. Box 189
Merrickville , Ontario K0G 1N0
Canada

Rick Morgan
Phone: 202-564-9143
Fax: 202-565-2156
E-mail: morgan.rick@epa.gov

EPA/OAR/OAP - Climate Protection Partnerships Division
1200 Pennsylvania Ave., NW (6202J)
Washington, DC 20460
USA

Gregory A. Norris, Ph.D.
Phone: 207-676-7640
Fax: 207-676-7647147
E-mail: norris@sylvatica.com

Sylvatica
Bauneg Hill Road, Suite 200
North Berwick, ME 03906
USA

Philippa Notten
Phone: 202-362-6357
Fax: 202-362-6357
E-mail: pnotten@netzero.net

University of Cape Town, South Africa
5415 Connecticut Ave. #140
Washington, DC 20015
USA

Michael Overcash
Phone: 919-515-2325
Fax: 919-515-3465
E-mail: overcash@eos.ncsu.edu

North Carolina State University
Department of Chemical Engineering, Box 7905
Raleigh, NC 27695-7905
USA

Jonathan Overly
Phone: 865-974-3625
Fax: 865-974-1838311
E-mail: jgoverly@utk.edu

The Center for Clean Products and Clean Technologies at the University of Tennessee
Conference Center Bldg.
Knoxville, TN 37996-4134
USA

Frank Princiotta
Phone: 513-569-7391
Fax: 513-569-7680
E-mail: princiotta.frank @epa.gov

US EPA, National Risk Management Research Laboratory
26 W. Martin Luther King Drive
Cincinnati, OH 45268
USA

Scott Properzi
Phone: +45 4480 6614
Fax: +45 4480 6604
E-mail: spx@e2.dk

ENERGI E2
Lautruphoj 5

Denmark

Beverly J. Sauer
Phone: 913-649-2225 Ext. 228
Fax: 913-649-6494
E-mail: bsauer@fal.com

Franklin Associates, Ltd.
4121 West 83rd Street, Suite 108
Prairie Village, KS 66208
USA

Rita Schenck
Phone: 206-463-7430
Fax: 206-279-157019001
E-mail: rita@iere.org

Institute for Environmental Research and Education
Vashon Hwy SW
Vashon, WA 98070
USA

Caroline Setterwall
Phone: +46 (0)223 55103
Fax:
E-mail: caroline.setterwall@swedpower.vattenfall.se

SwedPower AB within Vattenfall AB
Nedre Lasarbo 5
Sweden

John Sheehan
Phone: 303-384-6136
Fax: 303-384-6877
E-mail: john_sheehan@nrel.gov

National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401
USA

Timothy Skone, PE
Phone: 703-318-4604
Fax: 703-736-0826
E-mail: skonet@saic.com

SAIC
11251 Roger Bacon Drive
Reston, VA 20190
USA

Ray Smith
Phone: 513-569-7161
Fax: 513-569-7111
E-mail: smith.raymond@epa.gov

US EPA, National Risk Management Research Laboratory
26 W. Martin Luther King Drive, MS-466
Cincinnati, OH 45268
USA

Tom Tramm
Phone: 847-256-3553
Fax:
E-mail: t.tramm@att.net

Consultant
518 Washington Ave.
Wilmette, IL 60091
USA

Dr. Bo Weidema
Phone: +45 333 22822
Fax: +45 339 11103
E-mail: bow@lca-net.com

2.-0 LCA Consultants
Borgergade 6, 1.

Denmark

An International Workshop on
Electricity Data for Life Cycle Inventories
Introduction and Overview

Background:

The environmental consequences of electrical energy production frequently account for a major portion of the total environmental burdens identified in product Life Cycle Assessments, across a broad variety of product types, and across a range of impact categories. Therefore, accurate, complete, and up-to-date LCA information and data on electricity production is vital.

Modeling of the environmental burdens of electricity production is far from a simple or straightforward task. Indeed, the electricity supply system is among the most complex of all the industries addressed in an LCA. This complexity arises from a number of factors, including:

- the broad geographic scope of power grids and electricity markets with power wheeling.
- the dynamics of supply dispatch in response to demand changes, overlaid on daily and seasonal dynamics;
- the wide variation among generation stations in emissions and inputs per unit generation across and even within fuel types;
- the rapid ongoing evolution and regional variety of the electricity system and the regulatory environment in which it operates;
- the rapid and ongoing evolution of electricity generation technologies, and uncertainties about their future market penetration, and
- the potentially long time frames and importance of electricity consumption for the life cycles of durable products.

In the face of the increasing globalization of supply chains, we note at least two major limitations of currently available LCA data on electricity production:

- limited geographic coverage
- lack of consistency among databases for different regions, and even among alternative databases covering the same region

This lack of consistency among existing databases would be of only minor concern if there were a current consensus of approach to LCA modeling of electricity supply systems, *and* widespread effort to develop consistent data for all regions of the globe. Our assessment of the present situation is that there is neither. Fortunately, there appears to be growing recognition of the need for both.

Objectives of the Workshop

The purpose of the USEPA/NREL International Workshop on Electricity Data for LCIs is to make progress in response to the needs identified above, by providing a forum for:

- exchanging information on the state-of-the-practice of collecting and reporting electricity life cycle inventory data, and
- identifying technical assumptions and their ramifications in collecting inventory data.

In particular, the workshop is intended to facilitate the exchange of ideas and information on three fronts: methodological issues, ongoing and planned LCA data development efforts with an electricity component, and identification of best sources of data and models from which to build LCA models of electricity supply.

Format of the Workshop

A workshop of 2 and a half days is planned, for the dates 23-25 October, 2001. The location will be EPA's Andrew W. Breidenbach Research Center, Cincinnati, Ohio, USA. The workshop will move from initial plenary sessions to breakout working groups. The plenary sessions are intended to provide all attendees with a common basis of understanding of the life cycle perspective, the issues that are involved in collecting electricity data, and the specific discussion topics for the workshop. Workgroups will flesh out specific issues in more detail and work toward consensus. The topic areas planned for the workgroups are as follows:

- Average versus Marginal Systems Modeling
- Boundaries for Electricity Generation Systems
    - Environmental flows and releases
    - System definition
- New and Non-Traditional Electricity Generation
- Transmission and Distribution
- Outputs and Co-Product Allocation

Summary of Workgroup Topic Areas

Average versus Marginal Systems Modeling

Current LCA modeling represents an allocation of the total environmental burdens of a macro-system (e.g., today's economy) to the life cycles of individual products and services. All such LCAs are structured so that, theoretically, the results could be combined to form a total response. The goal is to answer the question: "If we were to assign the total environmental burdens caused by global demand for goods and services across all components of that demand, how much burden would we assign to each unit of good or service?" Heijungs (1997) referred to this question as "the attribution problem." Thus, for electricity generation, LCAs assign, or apportion, the burdens of a region's annual generation equally across each kWh of electricity produced and consumed. Thus, if the annual generation for a region comes from equal shares of particular energy sources, for example, hydro, nuclear, and fossil fuel prime movers, then each kWh produced and used in this region would be modeled as an "average kWh," produced from 1/3 hydro, 1/3 nuclear, and 1/3 fossil fuel. This is the approach taken in attributional LCA modeling.

An evolution is taking place within the field of Life Cycle Assessment, away from models of "average" systems which support retrospective analyses, towards models of "marginal" systems which support prospective analyses. In contrast to attributional LCAs, prospective LCAs explicitly attempt to characterize what the impacts will be of potential decisions. Thus, they are designed to provide insight about "what will happen if we decide A or B," rather than "which product is to blame for which burdens."

The processes whose levels of output will be impacted by a decision or a change in demand are referred to as the "marginal" processes – those producing "at the margin." .

At first blush, the marginal modeling underlying prospective LCA may appear more complex or data-intensive than the average modeling underlying attributional LCA. In practice, this is not necessarily the case, and in fact prospective LCA helps take some of the arbitrariness out of thorny LCI modeling issues such as allocation (Weidema 2001). In most if not all cases, the use of LCA for decision support appears to call for adopting the prospective approach as far as possible.

A number of inter-related questions arise in attempting to identify how the energy supply system actually responds to changes in demand, depending upon characteristics of the demand change including its location, timing, duration, and magnitude. In order to provide a sound basis for prospective modeling of the electricity supply system, we must address the following questions:

- What do we know about how the electricity supply system responds to changes in demand?
- How is this system's response to demand currently modeled, by what models and with what accuracy?
- How should LCA incorporate these understandings and perhaps the results of these models in its treatment of electricity?

Boundaries for the Electricity Generation Systems

LCAs attempt to approximate comprehensive treatment of the environmental, health and resource burdens associated with product systems. In theory, this comprehensiveness entails inclusion of "all significant" burdens (e.g., pollution releases, resource consumption flows, or other impacts) of "all" causally-connected processes. Thus, the system boundary for a life cycle inventory model requires a series of choices along two dimensions: environment and supply chain. In the case of a life cycle inventory database concerning the electricity supply system, we note the following boundary decisions which must be made:

1. Which environmental flows and other data needed for impact modeling should be tracked, how, and with what specificity, for processes in the electricity supply system? How should the cut-off criteria be determined?

2. Which activities and operations along the supply chain should be included? That is how wide and how broad should the system boundaries been drawn? (e.g., should capital equipment be included? transport of workers to the production sites? service sector inputs such as from designers, lawyers, accountants, advertising, etc.?)

Decisions related to establishing specific cut-off criteria to set boundaries for particular processes in the system under study, are properly left to the goal and scope definition portions of individual life cycle assessments, or to the protocol development phase of the LCI database projects. This workshop will seek to pool insights from prior and current LCAs of electricity systems concerning the broader boundary questions of what sorts of flows and what sorts of processes are important to retain in general when modeling the electricity supply system

This workgroup will address the multiple 'what is in, what is out?" sorts of questions which are fundamental to life cycle inventory analysis. The workgroup will address its topics in a pair of sequential sessions.

The first session on boundaries will address environmental emissions and releases. Key questions include:

- Based on prior LCA and non-LCA environmental evaluations of the electricity supply system, is there a set of air emissions for which reporting in LCI databases should be required ? Is it possible to define a recommended set of air emissions which it would be sufficient to include in databases? What are the principal data sources for the key air emissions, and are there important differences among them from country to country?
- Water releases – the same set of questions as posed above for air emissions.
- Additional releases (e.g., radioactive isotopes) – the same set of questions.
- Other impacts (e.g., thermal enrichment of water, land use, etc.) – the same set of questions.

A second work session will address setting the system boundaries which will be used to determine which mass and energy flows will be accounted for. Key questions include:

- What inputs besides fuels are essential/important to include, for different types of generation?
- How have input/output-based LCA analyses been used in the past to shed light on this question, and what have their findings been?
- What is the significance and suggested treatment of maintenance and repair inputs?
- What is the significance and suggested treatment of supporting infrastructure?

New and Non-Traditional Electricity Generation

As mentioned in the introduction, the electricity supply system is dynamic, with old technologies being slowly replaced by new. As interest in minimizing the environmental impacts of electricity generation increases, so will the ongoing development and evaluation of innovative electricity supply technologies. One arena of potentially influential use of LCAs of energy systems may be in environmentally evaluating and comparing new generation technologies. Characterizing them for LCA poses a whole new and different set of data and modeling issues.

There are at least three inter-related sets of issues involving LCAs of new and non-traditional generation. The first is simply how to model the new technologies in LCA. For new technologies which simply replace other point source generation facilities, this may not be a challenge. But how shall LCA characterize distributed generation, whether from the average perspective and from the marginal perspective?

The second set of issues relates to comparative evaluation of the new technologies, such as fuel cells, from the LCA perspective. LCA evaluations of nascent electrical generation technologies may inform policy and/or research prioritization among competing options. How can LCAs be performed in a consistent, holistic, and valid fashion for these systems which are marked by high degrees of uncertainty and technological volatility, as well as scarcity of data?

The third set of issues relates to the way in which LCAs of product life cycles will tend to treat new generation, and potentially to influence the demand for new capacity. The treatment of in-place capacity will probably need to be considered separately from the treatment of demand which drives new capacity. An example concerns the proper treatment of flow-limited renewable energy, such as wind power capacity in place. From a prospective point of view, no change in product demand (whether increase or decrease) will change the amount of electricity generated by wind power capacity in place – its output is fixed by nature. So how, if at all, should this wind capacity appear in the results of a prospective LCA.

Transmission and Distribution

The transmission and distribution infrastructure component of the electricity supply system has traditionally been accounted for in LCA on in terms of the expected average line losses, or loss of power due to electrical resistance in the system connecting the point of generation to the point of use. The amount of this loss depends on the length of the transmission, the voltage at which transmission occurs, the size of the conductor, and the manner in which electricity is transmitted. Common losses range between two to five percent of power being transmitted (EIRRG 1998). LCA researchers from Asian Pacific countries have identified additional issues associated with what might be termed "fugitive losses" of electric power, which is un-metered or un-identified electricity consumption.

In fact, there may be important reasons other than line power losses to include the transmission and distribution network within the scope of LCAs of the electricity supply system – namely, the environmental impacts of constructing, maintaining, and operating the systems themselves. Some environmental concerns raised in connection with electricity transmission and distribution lines include visual impacts, habitat impacts, noise (from high-voltage and ultra-high-voltage transmission), and others (e.g., any remaining concern about effects of electrical and magnetic fields?).

This work group will address both the energy losses associated with transmission and distribution, as well as the impacts of T&D infrastructure itself.

Outputs and Co-Product Allocation

Co-product allocation arises as an issue whenever a process produces more than one useful product. For example, steam turbine systems may sell both electricity and low pressure steam as useful products. When co-products are present, modelers must determine how much of the burdens associated with operating and supplying the multi-output process should be allocated to each of co-product. Modelers must also decide on how to allocate environmental burden across co-products when one is a waste stream that can be sold for other uses.

The ISO standards for LCA, particularly ISO 14041 related to inventory analysis, provide methodological guidance on this issue. But they call for practitioners to attempt to avoid allocation if possible; and secondly, to attempt modeling approaches which reflect the physical realities (i.e. mass basis) of the process in terms of how inputs and releases would be altered if the levels of output were altered for one or more co-products. In summary, proper application of the ISO guidelines on allocation requires a physical understanding of the co-product production processes.

The workgroup on co-products and allocation for the electricity supply sector could provide considerable value to the worldwide LCA community by providing clarity and consensus on allocation rules. It could also help by pointing to the data sources which characterize the geographic details of which plants and plant types in which regions are producing how much of the economically valued co-products; such information will assist in assessing transportation distances for other LCAs which include the use of these co-products.

Pre-Workshop Activities

Workshop invitees (those who are able to participate in person as well as all others who are invited but cannot attend the workshop) are asked to submit their thoughts on the five topic areas. The workshop organizers will review the submissions and compile the results for distribution before the workshop. Also, suggestions for on-line resources and documents relevant to the upcoming discussions are requested. Submittals are needed no later than

September 21, 2001.

The value of the workshop discussions will be greatly increased to the extent that participants are able to inform themselves about the issues ahead of time, and to refine their understandings through initial exchange of ideas. The benefits of the workshop will be more widely distributed by providing open access to the information, resources, and discussion points beyond those who are able to attend.

To facilitate your submittal of ideas and facilitate workgroup discussions, please use the following questions to guide your response. Or, if we are not asking the right questions, please let us know that, too.

Average versus Marginal

1. What are the advantages and disadvantages of both average and marginal approaches to LCI modeling for electricity supply? When is either approach warranted?

2. When applying average or marginal approach how should the following factors be accounted for, if it all:

   - Short-term changes (occurring hourly, daily, and seasonally) in the electricity source profile resulting from variations in a plants LCI profile as a result of varying operating efficiency/output due to local demand?
   - Short/Mid-term changes (occurring daily, monthly, or yearly) in the electricity source profile resulting from changes in the source of electricity due to changing purchase contracts to plants of a different fuel type and emission profile on a routine basis (potential affect of deregulation)?
   - Long-term changes (occurring in 5 – 10 yrs. or more) in the electricity source profile due to technology/process improvements?

3. When adjusting for expected changes in the electricity source profile (see Question #2), what is the appropriate time frame minimum level of uncertainty necessary to model the change for a site-specific source profile, and regional and national averaged source profiles (24-hour day, seasonal, other)?

4. Changes to the electricity source profile are occurring and will occur in the future, at what point do these changes significantly impact the LCI to a the point at which they become observable to the decision-maker (short-term, mid-term, and/or long-term changes)? Should this determine the level of rigor and uncertainty in modeling electricity supply?

Boundaries

5. Based on prior LCA and non-LCA environmental evaluations of the electricity supply system, is there a set of environmental interventions for which reporting in LCI databases

should be required? Is it possible to define a recommended set that would be included in all electricity LCIs?

6. Are there source specific/unique environmental interventions that should be considered (i.e., not overlooked in a standardized list, see Question #1)? For example, ecological effects of hydroelectric facilities on river ecosystems.

7. What inputs besides fuels are essential/important to include, for different types of generation?

8. Can knowledge gained from previous input/output-based LCA analyses be used to address Question #7?

9. What is the significance and suggested treatment of maintenance and repair inputs?

10. What is the significance and suggested treatment of supporting infrastructure?

New and Non-Traditional

11. How should distributed generation be modeled in attributional and prospective LCAs?

12. How can LCA be usefully and consistently applied to assist comparative evaluation and to guide design improvement for uncertain or rapidly evolving technologies?

13. What are the key modeling issues and data needs in bio-fueled generation, including modeling of agriculture or forestry?

14. How should fixed-flow renewable technologies (such as photovoltaic, wind, and run-of-river hydro) be treated in attributional and prospective LCAs,?

Transmission & Distribution (T&D)

15. How variable are line losses as a function of user class, region, and other factors?

16. What are the major impacts of T&D infrastructure in place – e.g., land use, habitat, other?

17. Are these impacts expected to be important within the scope of actual life cycle assessments – e.g., in comparison with impacts of electricity production?

18. What data sources are available for characterizing the impacts of T&D infrastructure?

19. What are the major impacts of construction and maintenance of T&D infrastructure, and are these expected to be important in the larger context?

Co-Products and Allocation

20. How should co-products and allocation be addressed when modeling electricity supply?

21. What are the co-products of electricity generation, by plant type?

22. What defines a co-product from electricity generation? For example, recreational service "output" of hydroelectric facilities. If so, how well-characterized is its value, and how should it be treated in LCA?

23. What are the physical relationships that relate variation in the levels of output among the co-products to variation in the required inputs and the environmental releases from electric power production?

24. Which of these co-products currently has market value, which others may have market value in the future, and should impacts of co-product use be considered? If so, how should the future market potential be addressed?

25. Other issues?

Bibliography

Heijungs, Reinout, 1997. *Economic Drama and the Environmental Stage.* Ph.D. Dissertation, CML, University of Leiden, The Netherlands.

Weidema B P, Frees N, Nielsen A-M, 1999. "Marginal Production Technologies for Life Cycle Inventories." *The International Journal of Life Cycle Assessment* 4(1):48-56.

B P Weidema, 2001. Avoiding co-product allocation in life-cycle assessment. Journal of Industrial Ecology. 4(3):11-33.

Electric Industry Restructuring Research Group, 1998. *Electric Industry Restructuring: Opportunities and Risks for West Virginia – Interim Report No. 5: Transmission Enhancement and Expansion.* West Virginia University, Morgantown, WV.

Pre-Workshop Responses

Received from:

- Bo Weidema, 2.0-LCA Consultants, Denmark
- Tomas Ekvall, Chalmers, Sweden
- Philippa Notten, University of Capetown, South Africa
- Wolfram Krewitt, German Areospace Center, Germany
- Rolf Frischknecht, ESU-services, Uster, Switzerland
- Caroline Setterwall, Vattenfall, Sweden
- Michael Overcash, North Carolina State University, USA
- Ivars J. Licis, Environmental Protection Agency, USA
- Gjalt Huppes, CML, The Netherlands

Thoughts on the five topic areas

By Bo Weidema, 2.0-LCA Consultants

1. What are the advantages and disadvantages of both average and marginal approaches to LCI modeling for electricity supply? When is either approach warranted?

Advantage of the average (attributional) approach is that much statistical information is provided in a form suitable for this approach. Also, it may be easier to communicate to lay-people without an economic or system-analytical background.

Advantages of the marginal (prospective) approach is that it provides results that are meaningful in a decision-making context, it can reduce data collection efforts substantially (since only data for the marginal production is needed, not data for the entire system), and it avoids arbitrariness in setting of system boundaries, notably in relation to geographical and technological boundaries as well as in relation to co-product allocation.

The average (attributional) approach may be warranted when seeking to allocate blame for past activities. The marginal (prospective) approach is warranted when analysing the consequences of a decison, i.e. as a decision-support. The marginal approach can also be applied to allocate blame for past activities, by using historical data valid at the time of the decision that led to the situation that you wish to allocate blame for.

2. When applying the average or marginal approach, how should the following factors be accounted for, if it all:

o *Short-term changes (occurring hourly, daily, and seasonally) in the electricity source profile resulting from variations in a plant's LCI profile as a result of varying operating efficiency/output due to local demand?*

o *Short/Mid-term changes (occurring daily, monthly, or yearly) in the electricity source profile resulting from changes in the source of electricity due to changing purchase contracts to plants of a different fuel type and emission profile on a routine basis (potential affect of deregulation)?*

o *Long-term changes (occurring in 5 – 10 yrs. or more) in the electricity source profile due to technology/process improvements?*

In a decision-making context, it will most often be the long-term influence which is relevant, i.e. the influence on the average long-term marginal. However, if you investigate a device that operates only at a specific time of day, week or season, it is relevant to look at the average long-term marginal for this specific energy supply, i.e. to distinguish peak electricity as a separate product.

3. When adjusting for expected changes in the electricity source profile (see Question #2), what is the appropriate time frame and minimum level of uncertainty necessary to model the change for a site-specific source profile, and regional and national averaged source profiles (24-hour day, seasonal, other)?
Follows from the above answer.

4. Changes to the electricity source profile are occurring and will occur in the future, at what point do these changes significantly impact the LCI to a the point at which they become observable to the decision-maker (short-term, mid-term, and/or long-term changes)? Should this determine the level of rigor and uncertainty in modeling electricity supply?
Follows from the above.

New and Non-Traditional
I am not really sure that I understand what is the problem here? It appears straight-forward to me.

Co-Products and Allocation
20. How should co-products and allocation be addressed when modeling electricity supply?
According to ISO 14041.

22. What defines a co-product from electricity generation? For example, recreational service "output" of hydroelectric facilities. If so, how well-characterized is its value, and how should it be treated in LCA?
In attributional LCA, a co-product is defined as one that contribute to the income of the producer. This definition can also be used in prospective LCA, although here there is no need for a sharp definition of co-products, since all outputs to technosphere, whether co-products or waste for treatment, can be modeled in the same way.

24. Which of these co-products currently has market value, which others may have market value in the future, and should impacts of co-product use be considered? If so, how should the future market potential be addressed?
Follows from the above answer. Future market potential for co-products can be assessed by the use of forecasting, as when collecting data for any other future process.

By Tomas Ekvall, Chalmers

Here are brief reflections to some of the questions in the Issues Paper:

Average versus Marginal

Comment: It is important to distinguish between two types of changes in the electricity system: causes (perturbations) and effects. Short-term perturbations have short-term effects; they can also have long-term effects. Long-term perturbations have long-term effects; in most cases, they also have short-term effects.

1. Average modeling results in information on the environmental burdens of the electricity system. Marginal modeling, in most cases, results in information on the effects on these burdens of changes that are made in the life cycle. Different information may be relevant in different cases (Ekvall et al. 2001a; enclosed). What we need is a procedure to identify what information is relevant in a specific case.

2. I don't understand the description of short-term changes. To my experience, electricity production in a power plant is not affected by changes in the local demand since power plants are connected in a regional, national or even international grid. Short-term changes do occur, however, due to short-term changes in the demand on the larger geographical scale.

Average modeling is typically based on averages over a year or more. If the changes in the examples significantly change these average data for the relevant system, an average model should ideally be based on average data reflecting the new situation rather than the old. An exception is when we make a comparative LCA were the change takes place in one alternative only. Then we need two average models, reflecting the old and new situations respectively.

In marginal modeling, the aim is to describe the actual consequences. In the Nordic countries, hourly and daily changes in the electricity demand - as well as some seasonal and yearly changes - are managed by utilising the storage capacity of hydropower. In the end most of these changes affect the marginal base load production. The exceptions are short- and mid-term changes that occur during peak load periods. But this may vary between different countries.

3. I don't see the relevance of modeling site-specific changes, since the power plants are connected in a grid (but this reflection is based on my experience from the Nordic electricity market). To me the only exception is if you do average modeling and the contract specifies that the electricity comes from a specific plant. In this case, site specific data should be used regardless of the time frame of the change.

4. Ideally, average data should reflect the average environmental burdens of the system at the relevant period of time. If the average is expected to change significantly within the time frame of the system or decision, this should be taken into account. In practice, this is rarely done. Marginal data probably change more rapidly over time. For long-term margins, this is because different investments decisions are at stake at different points in time. Different technologies can be at the margin during the time frame of a single decision or system. This is part of the reason why marginal data should be expected to reflect a mix of technologies rather than a single technology (Mattsson et al. 2001; will hopefully be available at the conference).

Co-Products and Allocation

20. This depends on whether you want to model the environmental burdens of the system or the consequences of changes that are made in the system. In other words, the question is related to the choice between average and marginal data (Ekvall et al. 2001b; enclosed).

24. It can be relevant to include impacts of co-product use if you want to model consequences of changes (Ekvall & Finnveden 2001; enclosed).

- Ekvall et al. 2001a.doc
- Ekvall et al. 2001b.doc
- Ekvall & Finnveden 2001.doc

Thoughts on Discussion Questions

By Philippa Notten, University of Capetown

Average vs. Marginal

1. The distinction needs to be made between modeling electricity supply for incorporation into a product/process inventory, and modeling to support decision-making within the electricity supply industry itself (e.g. choice of a desulphurisation technology on a coal-fired plant). For the latter, only the marginal approach would appear valid, consistent with the requirements of modeling prospective decision systems (Weidema et al., 1999; Wenzel, 1999). Although the marginal approach is probably the most methodologically defensible for the former as well, average "historical" type LCIs should not be discounted altogether. These types of LCIs, as commonly available in LCA databases, are indispensable for screening assessments, to determine the extent of the contribution of electricity supply to the overall product/process system inventory, and so to determine whether a more accurate marginal analysis is warranted. This is perhaps more clearly explained with respect to the foreground / background convention in LCI modeling (Clift et al., 1998) (where the background system is defined as the set of processes whose operation is not directly affected by decisions based on the study, other than the quantity of material (or magnitude of the function) input into the foreground system). Where electricity supply falls into the foreground system, a marginal approach will always be warranted, whereas an average approach will often be sufficient where electricity supply falls into the background system.

   The advantage of the marginal approach is its inherently lower uncertainty (both in terms of its avoidance of using average data and its avoidance of arbitrary allocation rules). A possible disadvantage of the marginal approach is the lack of readily available data, whilst the principal advantage of the average approach appears to be that this is what is currently available in LCA databases (although this may well change, as the value of the marginal approach is appreciated, and it becomes more common to publish inventories of specific technologies). However, a possible barrier to this may be that companies are more comfortable publishing LCI information as national or product wide averages (i.e. confidentiality issues). The disadvantage of the average approach is its high uncertainty. This could be improved by the definition of more relevant averages (e.g. regional rather than national or broad technology type), and better reporting of their variability and uncertainty. This would allow a more informed determination of whether electricity supply can appropriately be kept in the background system (i.e. the contribution to uncertainty of the electricity LCI needs to be evaluated in light of the overall inventory uncertainty).

2. Stochastic modeling approaches can be used to incorporate variability, i.e. the inventory is presented as a range of probable output rather than a single mid-point. However, to be meaningful, stochastic models need to be applied to the actual process models underlying the inventory, where the actual variability in the data samples can be incorporated, and correlations between inputs can be avoided by modeling the causal mechanisms.

   Changes in the source profile can be incorporated by modeling short-, mid- and long-term scenarios, where these can reflect changes in fuels and technologies (i.e. changes in the grid mix for the average LCIs, and changes within the particular technology for the marginal LCIs). Importantly, the stochastic models recommended to include process variability should also include data uncertainty, i.e. the input probability distributions should include uncertainty due to variability, as well as that due to the nature of the data (e.g. uncertainty in the quality of future fuel sources). In this way, the uncertainty associated with the future scenarios can be quantitatively reflected in the inventory, i.e. the fact that the long-term scenario has much higher uncertainty than the short- and mid-term scenarios can be reflected. Although estimating the uncertainty associated with the data is inherently subjective, there are methods which mitigate this to some degree (Weidema and Wesnæs, 1996), and even a subjective estimate of uncertainty is preferable to representing a highly uncertain future inventory with false accuracy, as a mid-point LCI or a stochastic model only incorporating variability would.

A further point regarding incorporating data uncertainty and variability in the LCI using stochastic modeling is that this may force a marginal approach, or at least, force the definition of more tightly defined average systems. This is because incorporating the variability within systems averaging widely different processes can result in such high uncertainty (i.e. such a wide range in the output) that no significant differences are able to be discerned between options in a comparative assessment (Notten, 2001).

3. This is probably most meaningfully related to the time-frame of the decision system in which the electricity supply LCI is to be used. For most mid- to long-term decisions, a seasonal or annual variability is reasoned to be most meaningful. This is because in such systems the uncertainty in the inventory is likely to be dominated by the uncertainty associated with modeling the future system (e.g. uncertainty in the future grid mix), and including a higher level of variability will be unnecessary. Similarly, in national/regional average LCIs, annual variability should be sufficient as the variability between the technological systems is likely to dominate the overall uncertainty / variability.

4. This will depend to a large degree on the particular country or region under consideration, i.e. in what time-frame is a significantly different generation technology envisaged being added to the grid? For example, in South Africa, the electrical utility is currently in a position of over-supply, so in the mid- to long-term additional capacity demand can be met by re-powering the “mothballed” stations and operating current stations at higher loads. The electricity profile will therefore not change significantly, as changes in the grid mix merely result in a shift between older and more modern coal-fired plants, the effects of which are relatively small (Notten, 2001). However, the point at which a non-coal source is added to the grid will significantly change the profile, especially from a marginal perspective.

   The “level of rigor” and the uncertainty of modeling will certainly be affected, since it is not possible to model future systems at the same level of detail as existing, demonstrated systems. The subjective estimation of uncertainty (see comments in 2) plays a much larger role in the modeling of future systems, since it is not possible to rely on the actual variability in data samples, as in existing systems.

Boundaries

5. This is difficult as the interventions able to be considered will be constrained by the data availability (the degree of development/demonstration of the technology, and the scope of the study), however, a default list of interventions towards which to strive would certainly be helpful. This would also be very useful in standardizing the use of aggregate interventions,

e.g. TSP, TDS. Water-related interventions where found to be particularly problematic when trying to compare across different LCIs, e.g. use of categories such as “sulfates”, “nitrates” etc, rather than individual components.

Also requiring standardization is how energy resources are defined in fossil fuel-burning systems. This is required because different systems may burn very different quality fuels, e.g. modern South African coal-fired power stations burn very poor quality coal (ash contents as high as 40%, and CVs as low as 14 MJ/kg), thereby “freeing up” coal resources for high revenue coal products. This ability to extend the life of the coal reserves needs to be reflected in the inventory (most simply achieved by defining a reference CV for coal reserves, and adjusting the mass of coal consumed accordingly).

6. Non-stack emissions should not be overlooked (e.g. dust from blasting during mining, and blown from waste dumps). The impacts associated with solid waste management in coal-fired systems are typically poorly assessed. Diffuse sources of water pollution (as distinct from pipe-discharges) are often overlooked. These include surface run-off from waste dumps and stockpiles, and water collecting in opencast mining pits. Leachate from waste dumps and stockpiles, as well as seepage from ash dams and pollution containment dams are similarly neglected, although their significance can be considerable (Notten, 2001).

7. In wet-cooled, coal-fired plants water treatment chemicals were found to be the next most significant inputs after fuels, particularly in stations using poor quality water sources (Notten, 2001) (this could be a feature unique to South African plants, where water availability constraints force a high degree of internal recycle and re-use within the water plants).

8.

9. This is not possible to decide without reference to a particular decision situation, where it can be assessed from a marginal perspective, i.e. if the proposed change is expected to significantly increase the maintenance (or supporting structures) required, it should be included.

10. (same as 9).

New and Non-Traditional

11. This points to the need to include transmission and distribution in the inventories of point source generation facilities, so that these can be compared on a consistent basis to distributed sources.

12. The need to include a quantitative consideration of uncertainty is critical here. It is essential to guard against the comparison of incomplete and thus incomparable systems (a comparison of single-point inventories constructed from inconsistent data sets is likely to be more misleading than useful). Qualitative LCA methods (e.g. Graedel, 1998) may be of more value than quantitative methods here.

13.

14. Attributional LCIs should not be a problem, other than recognizing that the materials of construction, life-times and use patterns will play a larger role than in conventional energy technologies. For prospective LCIs, perhaps these could be viewed as incremental changes? (discrete steps rather than gradual load changes).

Transmission and Distribution

15.

16. South Africa has a problem with bird mortality (eagles insist on nesting in the pylons).

17. Land use, possibly.

18.

19. Habitat loss, herbicides used in maintaining servitudes.

Co-Products and Allocation

20. Weidema's marginal approach (Weidema, 2001) appears the most meaningful for prospective LCIs.

    No allocation problem regarding the electricity product was encountered within coal-fired electricity production in South African (since no steam or heat is sold as a co-product). However a different allocation problem arises due to the modern South African power stations being designed to burn near discard-quality coal. Allocating burdens to the coal-fuel supplying the station is found to be very significant for those stations supplied by dual-producing collieries, which produce a high-quality export coal (requiring significant coal preparation), as well as a low-quality power station coal. This can be regarded as combined production, so can be modeled by a marginal analysis (keeping the production of one product fixed, by varying the other)(Weidema, 2001). For some stations, this combined production is made more interesting by the fact that the power station coal is made up of a blend of run-of-mine coal and discard (the waste product from export-quality coal preparation). The combined production is therefore able to reduce the mass of discard waste (the disposal of which has significant environmental impacts), as well as avoid the waste of energy resources discard coal represents. The "avoided" burdens approach is used here, where the power-station coal is "credited" with the avoided burdens of discard disposal. Very significant for the electricity profile is that the discard-fuel source is essentially burden-free, i.e. is not allocated any mining burdens other than the "avoided" burdens.

21.

22.

23.

24. A small volume of coal-ash is sold for use in cement products in South Africa. However, this volume is so small (less than 5%) it has negligible impact on the LCI.

References

1. Clift R., Frischknecht R., Huppes G., and Weidema B. P. (1998) Towards a Coherent Approach to Life Cycle Inventory Analysis. SETAC-Europe.
2. Graedel T. E. (1998) *Streamlined Life-Cycle Assessment*. Bell Laboratories, Lucent Technologies, Prentice Hall.
3. Notten P. (2001) Life Cycle Inventory Uncertainty in Resource Based Industries - A Focus on Coal-Based Power Generation. Ph.D., University of Cape Town.
4. Weidema B. P. (2001) Avoiding Co-Product Allocation in Life-Cycle Assessment. *Journal of Cleaner Production* **4**(3), 11-33.
5. Weidema B. P., Frees N., and Nielsen A.-M. (1999) Marginal Production Technologies for Life Cycle Inventories. *International Journal of Life Cycle Assessment* **4**(1), 48-56.
6. Weidema B. P. and Wesnæs M. S. (1996) Data Quality Management for Life Cycle Inventories - An Example of Using Data Quality Indicators. *Journal of Cleaner Production* **4**(3-4), 167-174.
7. Wenzel H. (1999) Life Cycle Assessment in Pollution Prevention: Trends in Method Development and Simplifications. In *Tools and Methods for Pollution Prevention* (ed. S. K. Sikdar and U. Diwekar), pp. 119-129. Kluwer Academic Publishers.

Feedback on background paper
US EPA/NREL Workshop on Electricity Data for Life Cycle Inventories

By Wolfram Krewitt
German Aerospace Center, Institute of Technical Thermodynamics, System Analysis and Technology Assessment, Stuttgart, Germany

General remarks
The issues described in the background paper provide a good summary of most relevant research issues in the field of LCA/electricity and thus sketch an interesting and exciting research agenda. From my understanding the list of issues suggest that the scope of LCA is getting much broader, and thus partly leads to overlaps with other scientific areas. While in general I very much appreciate this development, I think it is also very important to be clear about the inherent limitations of the LCA approach. I certainly don't want to say that LCA methodology should not be developed further, but I think it is necessary also to focus – in a positive sense – LCA activities to key areas where the LCA methodology has proven it's strength, and on the other hand to invest efforts in establishing well defined interfaces to other areas (e.g. energy system modeling) and thus gain from synergies. Let me try to illustrate this position with respect to two points arising from the background paper:

1) Local scale Impacts

Local scale impacts on ecosystem via land use, alteration of water systems etc. partly are the dominant impacts for decentralized renewable energy technologies. I think there are some inherent limitations to the LCA methodology in addressing such very local scale impacts. LCA is based on the capability of summing up specific parameters over a large number of processes, over time, and over regions. Recent developments explore the feasibility of site and time dependent LCA. A key problem of very local scale impacts is that it is not necessarily the technical characteristics of a facility, but much more the specific environmental conditions at a given site (soil quality, water regime, topography, ...) which determines the level of impact resulting from a 'unit' of environmental intervention. Technical parameters on the one hand and site specific environmental conditions on the other hand are very closely interrelated and cannot be evaluated independently any more. Summing up environmental interventions to an aggregated indicator is therefore very difficult, if not impossible. I think it is not without reason that up to now we do not have a satisfying approach for treating land use adequately in LCA.

I am currently working on a project on 'strategies for an ecologically optimized expansion of renewable energy sources in Germany'. The project includes LCA of renewable energy technologies, the integration of LCA results into the development of energy system scenarios, and has a specific focus on the consideration of aspects related to the conservation of nature which are traditionally not well covered in LCA. Impacts on local ecosystems, the disturbance of specific flora/fauna habitats etc. are key impacts for some renewable energies. Because of the strong site dependency of such impacts, I am more and more convinced that LCA is not the appropriate tool to deal with such impact categories. We need other tools, most probably GIS based, to ***complement*** information derived from LCA to support sound decision making.

2) Link to energy system modeling

Some of the issues addressed in the background paper under the heading of 'average vs. marginal systems modeling' are typically addressed by people that operate energy system simulation or optimization models, and are quite far away from the traditional process-chain oriented product LCA. This by no means says that LCA should not tackle such problems, but – again – we should be aware of inherent limitations, we have to be aware of what other people have developed with large efforts over many years, and we should seek to identify most appropriate interfaces to existing tools.

I recently initiated a project proposal to the EU which tried to combine LCA methodology and the TIMES-type of energy optimization models. Unfortunately the proposal was rejected, apparently we were not able to clearly communicate what we wanted to do, but I still think this a very interesting task. Even if the proposal did not make it, the proposal preparation phase was quite interesting, as we learned that it is not that easy to bring LCA people and energy system modelers together. One of the important points is the enormous complexity in quite different areas. Energy system models include many hundreds of individual processes to generate a realistic picture of supply and demand patterns over time. It is hardly possible to provide detailed LCA data for all these processes (do we need them??). On the other hand, in terms of environmental impacts most of the current energy system models focus on CO_2 emissions, and partly cover SO_2, NO_x and particles (do we need others??).

So, what I want to say in short: There is both a need and potential for further development of LCA methodology related to energy supply. But do not try to make LCA a 'universal' tool. Define reasonable links and interfaces to existing tools which already do a good job for specific tasks, and benefit from synergies.

Average versus Marginal

(1, 2, 3, 4) It seems that in general a marginal approach is preferable, as it better reflects the 'real' conditions. However, this certainly depends on the question at stake. The marginal change between status A and status B does not necessarily reflect differences in the characteristics of a specific product. Marginal impacts resulting from the decision A or B do very much depend on a large number of decisions taken by other actors in the complex system. Many of these decisions are not independent. Complex models are required to model the behavior of such a system (energy system simulation/optimization models). Is this still the scope of LCA?

The average approach seems to be relatively straightforward, but often the average inventory is extrapolated from individual plants for which a detailed inventory exists, but which do not necessarily represent the actual mix of different plants operated under different conditions. If reasonable assumptions are taken, the average approach might be more helpful to point out specific differences between products.

Most of the short-term and also mid-term changes in the electricity source profile have a regular pattern, so that a reasonable averaging should be used. I do not see a case in which conditions at a specific hour are really relevant for an LCA study. Long term changes need to be accounted. In the past, I mainly used annual averages.

Boundaries
(5) The European ExternE project on External Costs of Energy (as well as the joint US/EC Study on Fuel Cycle Externalities, which was a forerunner of ExternE) started with a screening of a range of pollutants and related impacts. Based on expert judgement (no formal selection procedure), a set of some few priority impacts and related pollutants was identified. External costs (as an aggregated damage indicator) were very much dominated by greenhouse gases, NO_x, SO_2, and particles (and related secondary substances, namely ozone, sulfates and nitrates). This conclusion was quite robust. Although the small number of key substances was often criticized for being inappropriate, other LCA studies for energy technologies with a more comprehensive inventory are also dominated by the same set of pollutants.

The picture will change with an increasing share of renewables, but the above mentioned pollutants still dominate LCA results for renewables technologies because of the importance of the conventional energy supply mix.

In the beginning of the project, ExternE carried out a reasonable screening of potential impacts from heavy metals and some few organics and concluded that for the broad range of fuel chains analyzed the impacts from these substances are negligible compared to those from the above mentioned priority pollutants. The current phase of ExternE explores in more detail potential impacts from heavy metals and organic substances, with a focus on emissions to soil and water. Results are not yet available.

In addition to air pollutants, the consumption of energy and non-energy resources should be included in the inventory. A problem for non-energy resources is of course to decide which are important. New technologies like fuel cells require some exotic materials at currently tiny quantities, but market introduction might lead to a significant demand in the future and thus lead to problems. For PV systems new materials are under development. Very difficult to recommend a default list.

(6) Yes, there are of course source specific interventions, often they are unique for a given plant at a specific site. As discussed above, I doubt whether LCA is the most appropriate tool to deal with such impacts in general, as they often depend on site specific environmental conditions rather than on the facility’s technical features. To give some examples, ExternE discusses for instance effects like increase in real estate value, improved commercial shipping, tourist attractions, and effects on the scenery in the catchment area resulting from a run-of-river plant at the river Danube in Austria. For a hydro project in Norway impacts of temperate water into a fjord on the ferry traffic are described and quantified. Noise impacts as well as visual intrusion might be important for wind turbines, but again the effect is very site dependent.

(7, 8) This of course very much depends on the technology. Of course for renewables the ‘other’ types of impacts are increasingly important (do you expect here a complete list??). Extended input/output tables are of course helpful to quantify emissions from these inputs, and also to identify the main source sectors. As an example the figure below shows results from a hybrid-LCA (process chain analysis linked to I/O analysis): the contribution of different processes (partly aggregated already in the diagram) to total CO_2-emisisons from a 5 kW PV roof application, and the respective contributions from process chain analysis and I/O analysis.

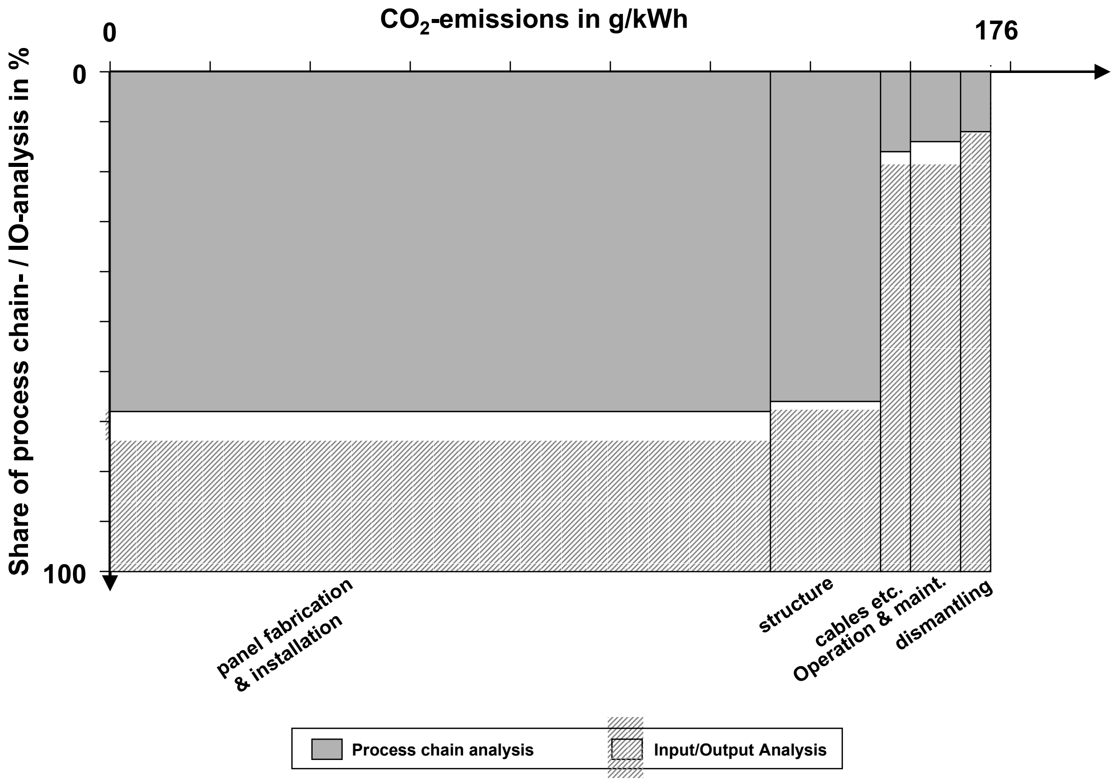


Fig. 1: CO_2-emissons from a 5 kW PV roof application

(9, 10) Impacts from maintenance and repair in general are relatively low (see figure 1) and might be well covered by I/O. What do you mean by ‘supporting infrastructure’?

New and Non-Traditional

(12) Germany aims at a share of 50% electricity from renewable energy sources in 2050, i.e. we have to expect a drastic change in our energy system. Current LCAs for emerging technologies however most often use the current electricity mix as an input to upstream processes. Besides of the obvious strive for getting the best available data for the relevant new materials (using also tools like technical learning curves etc.), it is important to use the characteristics of a future energy system with an adequate share of renewable energy as an input to basic processes in order to provide a more realistic picture of the emissions resulting from energy supply. It is of course not easy to agree on a specific future energy scenario, so the door is open for another source of potential differences between LCA studies.

(13) The agricultural reference system is of major importance. As also transport processes are important, the spatial pattern of supply of biofuels and the demand for e.g. district heating have to match.

(14) If we want to compare specific energy technologies to evaluate their potential for solving specific environmental problems, it is sufficient to look at the impacts normalized to a kWh at the power plant’s gate. If we want to take into account the capacity effect and a given supply task, we might take into account a back-up technology. I would prefer however to look at the

full energy system with a certain share of renewables, which again requires the use of an energy system model.

Co-Products and Allocation

I just want to give the example from ExternE, where we discussed in detail the allocation of impacts from a combined heat and power plant between the electricity and heat output (knowing that this is a problem that has been extensively discussed already in the past):

In ExternE we discussed the following allocation alternatives:

- Allocation based on operational characteristics (operation is heat or electricity oriented ➔ electricity or heat as by-product ➔ benefits of joint production are assigned to the by-product. We can also use the ratio of additional fuel input required for producing the „by-product" to the total fuel input required for both electricity and heat production.)
- Allocation based on thermodynamic parameters (energy or exergy content; several other parameters are discussed in the literature, taking into account various characteristics of the steam-process, but results achieved with these parameters generally are within the range covered by the energy content and the exergy indicators)
- Allocation based on the final products' price (Assuming a perfect market, the final products' price probably is the best indicator for the utility of the product. However, the price of electricity and heat is highly dependent on the customers demand characteristics and other non-technical parameters.)

As an example, the table below shows external costs (as an aggregated indicator of environmental impacts) for heat and electricity from a 520 MW coal fired CHP plant in Germany for different allocation rules:

	mEuro/kWh$_{el}$	MEuro/MJ
Credit for heat, substituting	2.7	
oil fired domestic boilers	5.0	
gas fired domestic boilers		
Credit for electricity		(- 7.8)
Additional fuel input	4.9	0.13
Energy content	2.3	0.64
Exergy	4.6	0.24
Price	3.6	0.38

(note that these numbers are taken from a 1996 ExternE report. External costs in this example are not based on the most recent ExternE methodology, but they still give a good indication on the effect of different allocation rules)

In ExternE we decided to report results based on exergy-allocation as mandatory, and in addition (optional) results based on energy content or price allocation to reflect specific conditions under which the CHP plant might be operated.

I do have some doubts to which extend it is possible to include secondary effects (like recreational effects from hydro plants, or the example from Norway given above in which the hydro project leads to effects on ferry traffic). These effects are very site specific and need a case by case evaluation. Often employment effects are mentioned as a positive effect resulting from the introduction of renewable energy systems. I recommend to not consider such effects in an LCA.

Input paper for discussion during the International Workshop on Electricity Data for Life Cycle Inventories

Written by
Dr. Rolf Frischknecht, ESU-services, Uster, Switzerland
10.09.2001

Overview

The present input paper is structured according to the issues paper distributed among the participants mid of August 2001. It contains some additional questions as well as possible answers to some of the questions listed. The answers given are not complete nor exhaustive. Further explanations will be given during the workshop.

I like to emphasise, that I very much appreciate the sophisticated level of the present version of the issues paper. It covers most of the pertinent and most important methodological topics.

Average versus Marginal Systems Modelling

In order to be able to discuss the issue in a well-structured way, I suggest to first try to link the way of modelling to the different questions/goals of an LCA (see, e.g., Tab. 5.9 in Frischknecht (1998)).

I like to precise the first question and add the two following questions (see also Chapter 5 in Frischknecht (1998)):

- What do we know about how the electricity supply system respons to **<u>different levels</u>** of changes in demand (from short term changes like unexpected increase in demand during the day to long term (20 to 40 years) development of electricity consumption)?
- How to separate replacement (of old equipment) from expansion of production when performing a prospective LCA?
  Some of the marginal technologies are rather used to replace old equipment instead of increasing the production capacity. Hence marginal technology mixes should be determined carefully.
- What is the relation between overall market size of a product/service and its respective individual products?
  Overall market trends are often used to determine marginal technologies. Environmental and energy policy may be used to limit the overall energy consumption or the overall environmental pollution. However, LCA is rather suited to help finding an optimal allocation of "pollution rights" among all products/services on a micro-economic level. Therefore a relation between macro- and micro-economic perspectives should be established in one way or another.

Boundaries for the Electricity Generation System

Additionally to the two boundary dimensions "environment" and "supply chain" I would add two additional ones concerning time and geography:

- When modelling the supply with a certain electricity mix, which geographic area is adequate to represent the mix? Some LCA experts argue for instance that for the Swiss electricity supply system the western European integrated electricity network (UCTE) is the adequate electricity mix due to the intensive trade relations.
- Pollution from electricity supply systems may occur in the very far future (e.g. long-term radionuclide releases from abandoned uranium milling sites). How shall such emissions

be treated? How should we treat the treatment and disposal of radioactive wastes? How should discounting be applied in LCI of electricity systems (positive, zero, negative discount rate), see e.g., Hellweg (2000:125ff.)?

- Besides capital equipment, transport of workers to the site etc., research and administrative divisions should explicitely be addressed when asking about system boundaries.

New and Non-traditional Electricity Generation

Concerning new electricity generating technologies my major concern is about the correct way of modelling it, again depending on the goal of the LCA.

Do we need a dynamic model to assess the environmental impacts of (the introduction of) new technologies in order to answer the question whether these technologies should be favoured or not? Or, would it be sufficient to model a possible future (steady) state (when the technology is more or less established)?

The correct treatment of flow-limited sources such as wind or hydroelectric power refers to the question about the relation between the macro- and microeconomic situations. To my understanding LCA is a tool which helps to allocate scarce environmental resources and scarce "pollution rights" among competing products (like the price system is used to efficiently allocate the scarce traditional production factors human power, capital and land). Hence, macro-economic limitations like the ones mentioned should not have an influence on the way the LCA is carried out.

Transmission and Distribution

It should be precised on which level of voltage the losses are reported. On the low voltage level (380V), losses more than 10% are not unusual. On higher voltage levels, losses are much lower (below a few percents). Additionally power switching stations (SF_6-losses) and operation of high voltage transmission lines (N_2O-emissions) are important.

Outputs and Co-Product Allocation

Concerning co-product allocation I like to refer to my article written in the Int.J. LCA, Vol.5, No. 2,pp.85-95 or Chapter 7 of my Ph.D. thesis.

Questions

Average versus Marginal

1. The choice whether to use a marginal or an average approach depends on the goal of the study (see, e.g., Tab. 5.9 in Frischknecht (1998)).
2. See excerpts from Chapter 5 of Frischknecht (1998), especially Subchapter 5.3.
3. dito
4. Decisions which affect the electricity demand within a production site (on the short, long, or very long term) should adequately be reflected in the LCI model. Hence, only long-term changes in the electricity supply mix should be considered in a long term decision situation for instance.

Boundaries

5. An adequate treatment of direct ecosystem impairment caused by hydroelectric power production, coal, oil and uranium extraction is still missing. I am not sure whether these impacts may ever be considered adequately. Nuclear waste disposal is another issue where an adequate assessment within LCA is still missing. Noise seems to get more

attention in connection with wind power. Also here, broadly accepted inventory parameters and impact assessment methods are still missing.

6. If LCI/LCA data should be used in a labelling scheme for green electricity, I recommend to additionally include local criteria which cannot be considered in standard LCAs. This is successfully done within the "naturemade star" label for environmentally excellent electricity from reneweable sources (see http://www.naturemade.org). It covers aspects like river ecosystems, agricultural techniques, visual impacts of wind power plants etc.
7. Catalysts and especially precious metals are important due to the high environmental loads per gram. Capital equipment is (obviously) relevant for new renewables such as photovoltaics and wind power but also for hydroelectric power plants. I have no idea about the environmental relevance of research and administration (flights). For hydroelectric power plants care must be taken not to neglect methane emissions if substantial amounts of biomass have been drowned by the artificial lake.
8. We have little experience on input/output-based LCAs. We applied it to roughly estimate the contribution of prospection (assuming that 50% of the amount of money spent for prospection is used for computer equipment). It was a very minor contribution and we therefore excluded prospection from the analysis.
9. Reliable data is rare to answer this question.
10. Concerning conventional fossil fueled power plants it seems rather negligible (except for land use aspects). For other sources (see answer to question 7.) it is the main contribution.

New and Non-Traditional

11. I am not sure whether I understand the question. I see no (principal) difference in analysis depending on the degree of distribution of a power plant technology.
12. Comparative evaluation and design improvement are two completely different LCA goals. While the first needs data about the current situation (in order to improve it), the latter requires an analysis of a future situation where production processes and technologies needed for a new power plant type are optimised. The question can then be answered whether it is worthwhile (from an environmental point of view) to develop such a technology at all.
13. Bio-fuels are included in the natural cycle of chemical elements. I consider the adequate modelling of nutrients and trace elements cycles as important aspects. Furthermore, the influence of agriculture/forestry on biodiversity and carbon balance (carbon fixing in the topsoil of forests) may also be important.
14. No special treatment. Reasons are given above.

Transmission & Distribution (T&D)

15. Losses are very much dependent on the level of voltage (corresponding to your term "user class"?).
16. One major impact is of course due to the losses (and therefore depending on the environmental quality of the power plant mix). Land use, influence on biodiversity etc. may also be relevant. However, these aspects cannot yet adequately be considered. We should not forget the emissions of SF6 in power switching units and the production of N2O of high voltage power lines.
17. I expect electricity losses and SF6-emissions to be important (or at least not negligible).
18. The Ökoinventare von Energiesystemen" (Frischknecht et al. 1996) provides an overview of the Swiss network. It excludes SF6-emissions, however. Any utility should have data on their T&D infrastructure (and operation).
19. See above.

Co-products and Allocation

20. To my opinion there is no general rule or approach that is acceptable for all parties involved nor sensible for all situations (see Frischknecht 2000).
21. coal: electricity, heat, gypsum (building industry), fly ash (cement production)
    oil: electricity, heat, gypsum (?)
    natural gas: electricity, heat
    coke oven gas: disposal of "residual gas" of coke production, electricity, heat
    blast furnace gas: disposal of "residual gas" of iron melting, electricity, heat
    nuclear power: electricity, heat
    hydroelectric power plant: electricity, flood protection, irrigation, recreation, fishing
    photovoltaics: electricity, weather protection (if integrated in slope roofs, façades)
    combined heat and power units (motors, fuel cells): electricity, heat
    biomass: electricity, heat
    waste incineration: treated wastes, heat, electricity, slags (cement industry)
    biogas from manure: treated manure, heat electricity
    biogas from organic waste: compost, heat, electricity
    biogas from sewage sludge treatment: conditioned sludge, heat, electricity
    geothermal power plant: electricity, heat, therapeutic baths (e.g. the Blue Lagoon, Iceland)
    General comment: in many cases, heat is not used but emitted to air and water.
22. I suggest (as a pragmatic solution) to limit "real" co-products in relation to a certain share of total proceeds (e.g. >10%).
23. I think this is not the right question. Think about a spark ignition engine, which at the same time produces electricity and heat. One may operate the engine in a way that only electricity or only useful heat is being produced. However, investment calculations have been made on the basis to use both products as much as possible. It makes therefore no sense to vary one of the products in order to determine the environmental releases to be attributed to this product. The CHP plant is a **joint** production unit because of economic reasons. Hence, economic considerations may overrun mere physical considerations.
24. Current market values are delicate without considering the development of the overall markets. However, I do not see too many difficulties here, except maybe power plants burning blast furnace and coke oven gases.

Other issues

25. The issue of discounting future activities and environmental releases and related to that of an appropriate time horizon. See also our paper on health impacts due to ionising radiation (Frischknecht et al. 2000).
26. The issue of an appropriate geographical boundary when analysing electricity supply mixes.
27. The issue of rather using LCI data of entire decision units (the utility as a whole; divisions within a utility) rather than of their individual production technologies, when dealing with electricity supply mixes.

References

Frischknecht R., 2000. Allocation in Life Cycle Inventory Analysis, in *Int.J.LCA*, Vol. 5 No. 2, pp. 85-95

Frischknecht R., 1998. *Life Cycle Inventory Analysis for Decision-Making; Scope-dependent Inventory System Models and Context-specific Joint Product Allocation*, Ph.D.-thesis Nr. 12599, Swiss Federal Institute of Technology (ETH), Zürich

Frischknecht R., A. Braunschweig, P. Hofstetter, P. Suter, 2000. human health damages due to ionising radiation in life cycle impact assessment, in *Environ.Ass.Rev.*, Vol. 20, No.2, pp. 159-189.
Frischknecht R., P. Suter (Eds.) et al., 1996. Ökoinventare von Energiesystemen, 3rd updated edition, Bundesamt für Energie, Bern, ISBN 3-9520661-1-7
Hellweg S., 2000. Time- and Site-Dependent Life-Cycle Assessment of Thermal Waste Treatment Processes, Ph.D.-thesis Nr. 13999, Swiss Federal Institute of Technology (ETH), Zürich

Submittal of ideas
Caroline Setterwall, Vattenfall

Average versus Marginal

Systems to be studied in a life cycle perspective have several life phases: construction phase, operation phase, demolition/dismantling phase and use phase. If you are studying an existing system the construction phase is historical and the demolition phase will come in the future whereas system operation and product use is happening all through the life time of the system. The real electricity supply probably varies through the life cycle and the mix of power generation systems as well.

Vattenfall always uses data describing today's technologies also for historical and future system processes. I.e. our LCA results never mirror the real environmental impact caused by the studied system throughout the life cycle. The results reflect a potential impact under certain defined circumstances.

If we know the electricity supplier in a life cycle process we try to find out the electricity generation mix (percentage hard coal based generation, nuclear, hydro etc.) of this supplier. If that is impossible we use the average generation mix per year of the country or the region (IEA Statistics). We use today's mix for both historical and future processes. Our attitude is that a summation of LCA study results of every system should not extremely exceed the actual environmental impact. You shouldn't burden one electricity needing system for the fact that marginal electricity generation is needed in a electricity generation system to secure deliveries to all consumers.

If the goal of a LCA study is to describe an extension of a system, i.e. a future production increase or a planned system which will need so much electricity that the electricity balance in a region or country will be influenced a marginal approach is appropriate.

The approach is however dependent on the goal of the LCA study and you should always try to be more specific and detailed in your descriptions and calculations of subsystems contributing the most to the environmental impact of the studied system. Sometimes it is appropriate to model different scenarios to deliver a diversified picture of a systems environmental impact.

Boundaries etc.

Generally can be said that for power systems using a fuel, handling of this fuel throughout the life cycle is crucial with respect to environmental impact whereas for other power systems the construction phase is more important. Vattenfall has the ambition to study those sub-processes in detail, which contribute largely to the environmental impact of the system, whereas other sub-processes are studied with a lower degree of exactitude.

For all kinds of power systems Vattenfall makes inventories of the system's construction phase, fuel production phase, operation phase including reinvestments and waste handling of fuel residues and demolition phase (for hydro power no demolition is considered, but a higher degree of reinvestment instead).

Vattenfall has been working with LCA since 1993 and has till now studied specific existing plants, most of them owned by Vattenfall. The following power systems have been studied in an LCA perspective:

- Nuclear power (2 plants with together 7 reactors, BWR and PWR, 2 mines, 2 enrichment sites)
- Hydro power (3 stations representative for the generation in a Swedish river (the Lule river, Vattenfall is now studying a second river))
- Oil-condensing (1 plant, reserve power)
- Oil-based gas turbines (1 plant, reserve power)
- Natural gas with gas and steam turbines (1 prospected plant, with gas delivered from different sites)
- Coal-condensing (3 plants in Denmark with coal deliveries from different sites)
- Biofuelled combined heat and power (1 existing plant fired with either energy forest (salix) or forest residues)
- Fuel cells (2 plants fuelled with natural gas)
- Solar cells (based on a Dutch study, adapted to Swedish conditions)

The construction phase is inventoried with respect to major construction materials and transports of those materials. Data for fabrication of components (generators, turbines, transformers etc) is often hard to get and is therefore often neglected but manufacturing of the raw materials for these components is included. Mostly the amounts of the following construction materials and processes are inventoried and followed to the cradle:
Steel
Concrete
Copper
Aluminum
Other metals
Plastics
Rock wool
Wood (mould wood)
Ground work (blasting mass handling)

For certain power systems there are special materials, which are important for instance catalysts in fuel cells or solar cell material. Till now Vattenfall has neglected electronics due to lack of manufacturing data but we will eventually start an inventory of electronics in different plants to find out the relative impact of such components.

Data about **fuel extraction and processing** is obtained from fuel suppliers or from literature. All steps are inventoried including transports and storage.

Data concerning **the operation phase** is retrieved from the plants' environmental management system (ISO 14001 or EMAS) or from the environmental report, which is sent to the authorities. These data include site-specific emissions to air, water and ground, consumption of bulk chemicals and fuels and generated waste. Reinvestments are considered (often a percentage of the construction phase). Following parameters are often included:
Fuel amounts
Use of bulk chemicals and cooling media

Use of land
Emissions from fuel use
Radioactive emissions for nuclear power
Site specific process emissions (for example ammonia from NOx-reduction measures)
Emissions of cooling media
Emissions of greenhouse gases due to overflooding of land in connection with dam construction (hydro power)
Fuel residues
Wastes

Production of inputs is included but not the construction of the production sites.

Transport emissions and fuel use are included all through the life cycle but fabrication of vehicles and roads etc is excluded.

In the **demolition phase** assumptions are made regarding recycling degrees and waste-handling options of different waste fractions based on today's technologies.

Impact on biotopes is an important issue in several activities connected to electricity generation, hydro power operation, mines etc. Vattenfall has developed a special method to describe biotope changes quantitatively: **The Biotopmethod**.

In the last years Vattenfall predominately has used the LCA methods described in ISO TR 14025 about Environmental Product Declarations (EPD) (you'll find the Swedish requirements based on ISO TR 14025 in English at http://www.environdec.com/eng/doc/pdf/e_epd_msr19992.pdf).

The utilities in Sweden have developed Product-specific Requirements, which are adapted for electricity and heat LCAs for EPDs (you'll find them in English at http://www.environdec.com/psr/e_psr9801.pdf).

Till now Vattenfall has two third party certified EPDs, *Hydro Power Electricity from the Lule River* and *Electricity from the Nuclear Power Plant at Forsmark* (http://www.environdec.com/eng/registrations.asp).

Thoughts on the 5 topics

By Michael Overcash, North Carolina State University, USA

Average vs Marginal

The increase accuracy of a marginal approach is probably not easily used since the errors in other aspects are often large.

In a marginal analysis there is still debate over what is the marginal plant. Just because others are using the average of plants it is unclear that the incremental plant is coal, nuclear, hydro, etc. It is kind of like who was in line first and not how is the whole system operating.

Boundaries

Not sure there is a lot here. The boundary should be as transparent as possible and then let people decide how big.

New and Traditional

There is already a good deal of work on new sources. The goal is to make these transparent

Transmission

We use 1.8% transmission losses as the high voltage case for main power delivery. I am not sure what the losses are under transformers and then local delivery. There is a real difference between residential and industrial.

Co-products and allocation

We use mass and try to break down processes into enough detail so that the emergence of a co-product is clear and can be allocated (the micro-allocation approach).

Ivars J. Licis
U.S. Environmental Protection Agency

I have already mentioned some of this to May Ann C., but just for the record:

MACRO vs MICRO
I see the issues you and this workshop raise as falling into two major classes, the Macro and the Micro class of issues.
The Macros deal with the purpose of the "data", or the whole LCA of electricity activity, (step one in LCA 101) and the setting"boundaries", the Micros start to dabble (OK, focus) into the refinements, including such things like the geographic differences, average vs. marginal, et al. While both classes contain topics of interest, the Macros seem to need defining earlier (maybe with some iteration). Within the framework of one workshop, I would guess we could not tackle more than the Macro, but who knows. Mary Ann has indicated that significant work on the Macro level has been done by others earlier. This will be helpful.

MOVING TARGET
There is another consideration that can bedevil the best of our intentions. We are tackling the electricity issue at a time that it is far from a stationary target and , if anything, it will be in an accelerating mode. I would attribute this to things like deregulation, distributed generation, environmental pressures and regulations coming into force in the short term, expected rise in fossil fuel prices (maybe with the exception of coal-if you do not have to count environmental requirements and carbon taxes) rise in population and a threat of global climate impact (believed by many as probably the largest environmental danger if not THE largest danger).
We should not be looking at how electricity has been made up to now, but rather how it will be made in the coming ----- years. This puts a different spin on it and what and how data may need to be gathered.

With this in mind, deliberating what time period this is aiming for has major implications (under Macro). Additionally, including, new technology can not be given a secondary level of inclusion for anything but the shortest time horizons (I realize nobody said they would, but I found some handwriting between the lines) which may or may not be enough to arrive at a usable end product.

On the other hand, getting a fast start on gathering "some" specific data can be useful, most of all for the purpose of moving up on the learning curve of what happens when you actually start beating the virtual bushes for it. It may not be the that such data gets actually used but serves a way to get a lot more insight into what is really needed, what can be had and what to do about thedifference and to a data base design.

My feeling is that we don't know enough about the design of this activity to just go out and do it. By no means am I suggesting this is not worthwhile. I am suggesting that this may be more like the war against terrorism vs. Operation Rolling Thunder, and the Macro end will demand more attention than I think we have allowed for it.

PURPOSE OF LCA DATA
My understanding is that Mary Ann feels that this data will not be used for the purposes of comparing energy sources (and it is her workshop). My prejudice is that, coming from the EPA,

it HAS to be able to be used for that. When the EPA says that this has more impact than that, where is the impact being considered?

My impression is that it is at least at some national level, not at a given facility or even industry sector, and the rest of the country is not involved. As soon as we start looking at electricity, we are looking at ALL the industrial and domestic sectors. It is closer to considering "what if everybody took this as EPA's advice?" . That is what this integration, multi-media, multi-impact, LCA' ing is about, I believe.

As soon as more than one energy technology for making electricity is assessed, some kind of *defacto* comparison has been made. Even if we personally do not let the two sets of information come close to each other, this comparison is unavoidable. There is uncertainty about new technologies and how to model them, that is true. There may be equal uncertainty about the existing collection of grandfathered power plants if we look to a future with the things mentioned above. I do not believe we can take a snapshot of "NOW" in the electricity sector and use it even if it's a lot more convenient. To me, this illustrates the need for the workshop to air out these issues at the Macro end.

HOW TO HANDLE "IN-PLACE CAPACITY"
"In-place capacity" should not be a separate issue, Energy is just about never where most people live (Iceland may be the big exception). Coal and oil are shipped large distances. So is electricity.

What's common here? The cost and impacts of the processes to do so. The same goes for wind, solar, wave, biomass, and even geothermal. If something is "closer", it probably costs less and probably requires less energy loss to get to the user AND maybe less of an impact. That's one part that needs to be determined, distance and means of transport. vs. impact.
A little heard of issue is number of people these activities require and the impact that generates. One could consider driving to work, the "work station" and its support and the infrastructure that supports all of that and the electricity part of the above.

Lastly, the energy beast (and electricity in particular) is different (from, say, diapers) because each and every supporting resource represents the use of energy and its impacts.
This seems to make a tightly intertwined web or tangle. Each little portion appears minuscule by itself but there are a lot of them, they are not all of equal impact and therefore may be significant.

Without some specific information to the contrary, deciding to leave out areas is tricky if not dangerous (Example: maintenance-a significant activity in boil-and-burn processes, still our most popular technology). We need to ASSESS what actually goes there or even better, have a certified expert at the workshop with info in hand.

QUESTIONS, MODELS AND DATA IN LCA
NOTE FOR THE INTERNATIONAL WORKSHOP ON ELECTRICITY DATA FOR LIFE CYCLE INVENTORIES

Gjalt Huppes
CML, Leiden University, Netherlands
huppes@cml.leidenuniv.nl
www.leidenuniv.nl/cml/ssp/

Contents:

Summary

Data become information when they are gathered adequately for a purpose, as one envisaged application. As several applications exist each requiring their own and different data, a first step is to specify the purpose for which data are gathered. A first choice is that data are to be used for improved decision making, by indicating effects of choices. This quite common assumption implies that we use data of the past to indicate future effects, involving some sort of **causality** as incorporated in a model structure. Depending on the question we want to answer, different causalities are involved. Causalities can be arranged systematically only in a model, so we should have models. The model, fitted with appropriate data, can indicate future effect. Here the focus is on LCA-type of models, a model with a very simple structure. Although depicting economic processes and their relations, they lack main economic mechanisms like supply and demand relations. Some bandwidth still exists in the group of simple LCA models.

There is a basic level of LCA model, where average yearly scores suffice to operate the model, and to give answers on a specific group of questions. More sophisticated questions require more sophisticated models. These make sense only if they also incorporate more sophisticated data. Especially questions related to system dynamics are scientifically interesting and have great practical importance. However, they lack a standardised model framework to systematically guide data development. Optimisation models, the non-dynamic ones, may be more easily operationalised but require an explicit normative framework: what is to be optimised? Given questions on choices we want to specify effects for, and models for answering them, then the requirements on data can be specified for making these models operational.

For long term development, setting up data bases on unit processes should be prime focus, kept separate as much as possible from model and methods dependent processing of such data, and from aggregating them into (sub)system using some always contentious model. Viewing current results from EGRID, a few conclusions can be drawn: keep unit process data pure, absolutely separated from applications requiring allocation, subtractions etc, and make them complete, including capital goods, maintenance and other overheads. They then may serve as many purposes as possible, including a role in the causal analysis of LCA modelling.

Suggested Reading

Dones R., Ménard M., and Gantner U. "Choice of Electricity-Mix for Different LCA Applications." 6th LCA Cases Studies Symposium. SETAC-Europe. 1998.

Dones R., Gantner U., Hirschberg S., and Doka G., Knoepfel I. "Environmental Inventories for Future Electricity Supply Systems for Switzerland", PSI Report No. 96-07. 1996.

Ekvall T. and Finnveden G."Allocation in ISO 14041 – A Critical Review." J. of Cleaner Production, Vol 9(2001). pp 197-208.

Ekvall T, Molander S., and Tillman A.-M. "Marginal or Average Data – Ethical Implications." 1st Int'l Conference on Life Cycle Management, Copenhagen, Denmark, Aug 2001. pp 91-93.

Ekvall T. "System Expansion and Allocation in Life Cycle Assessment: With Implications for Wastepaper Management." PhD Thesis. Technical Environmental Planning. Chalmers University of Technology. Gothenburg, Sweden. 1999.

Frischknecht R. "Allocation in Life Cycle Inventory Analysis for Joint Production," *Int J of LCA* 5(2), pp 85-95. 2000.

Frischknecht R. "Life Cycle Inventory Analysis for Decision-Making; Scope-dependent Inventory System Models and Context-specific Joint Product Allocation: Section 5. LCA for Decision-Making: The Advantage of Marginal Consideration." Excerpt (pp 47-79) from PhD. Thesis Nr. 12599, Swiss Federal Institute of Technology (ETH), Zürich, 1998.

LCA: Livscyklusvurdering af Dansk El og Kraftvarme. "Life Cycle Assessment of Danish Electricity and CHP." Summary. October 2000.

Michaelis P. "Royal Commission Environmental Pollution Study On Energy And The Environment: Paper prepared as background to the Study Life Cycle Assessment of Energy Systems." Centre for Environmental Strategy, University of Surrey. March 1998.

"Vattenfall's Life Cycle Studies of Electricity." Vattenfall, Stockholm, Sweden. October 1999.

International Workshop on Electricity Data for Life Cycle Inventories

Summary of Feedback on Issues

Prepared by
Mary Ann Curran, US EPA
Timothy Skone, SAIC
Alina Martin, SAIC

18 October 2001

Introduction

In preparation for the workshop, invitees were asked to submit their views and ideas on five key issues that relate to data collection for electricity. Written comments were submitted by nine individuals.

Universities	
1	North Carolina State University, USA
2	University of Capetown, South Africa
Consultants	
1	2.-0 LCA Consultants, Denmark
2	ESU Services, Switzerland
3	Orion Corp, New Zealand
Electricity Suppliers	
1	EDF, France
2	Vattenfall, Sweden
Researchers	
1	ITT, Germany
2	US EPA

Also, several published pieces were submitted for consideration (listed in the bibliography).

The responses have been compiled and are summarized below. Each issue area as presented in the original Issues Paper (August 2001) is presented in italics at the beginning of each section for easier reference.

The following themes were repeated throughout the comments:

1. Focus is on LCI issues, to avoid confusion with impact assessment.

2. The approach for data collection of electricity depends on the objective of the study.

3. Transparency is essential in drawing boundaries, etc.

Footnote: It is important to note that while at times the term LCA may be used, the focus of this discussion piece and the follow on workshop is to discuss life cycle inventories.

General Remarks

Before discussing the responses that were given on the key issues, it appears that respondents fall into two distinct camps when thinking about the modeling and application of the electricity life cycle data. Some respondents, such as the power generators, are interested in creating an LCA that focuses on the power generating facility, while others focus on the need to model electricity production data that can be used in any product LCA. One respondent worded it this way:

"The distinction needs to be made between modeling electricity supply for incorporation into a product/process inventory, and modeling to support decision-making within the electricity supply industry itself (e.g., choice of a desulphurisation technology on a coal-fired plant)."

We may need to address both of these limits or any other variations in between, but the important thing is to keep these objectives separate and clear.

It is very important to be clear about the inherent usefulness of the LCA approach and to focus on where it has proven its strength. At the same time, LCA should be interfaced with other areas (e.g. energy system modeling) and thus gain from synergies. Energy system models include many hundreds of individual processes to generate a realistic picture of supply and demand patterns over time. It is hardly possible to provide detailed LCA data for all these processes (do we need them?). On the other hand, in terms of environmental impacts, most of the current energy system models focus on CO_2 emissions, and partly cover SO_2, NO_x and particles (do we need others?). There is both a need and potential for further development of LCA methodology related to energy supply for energy systems into a product/process inventory and modeling to support decisions-making within the electricity supply industry.

Average versus Marginal Systems Modeling

Current LCA modeling represents an allocation of the total environmental burdens of a macro-system (e.g., today's economy) to the life cycles of individual products and services. All such LCAs are structured so that, theoretically, the results could be combined to form a total response. The goal is to answer the question: "If we were to assign the total environmental burdens caused by global demand for goods and services across all components of that demand, how much burden would we assign to each unit of good or service?" Heijungs (1997) referred to this question as "the attribution problem." Thus, for electricity generation, LCAs assign, or apportion, the burdens of a region's annual generation equally across each kWh of electricity produced and consumed. Thus, if the annual generation for a region comes from equal shares of particular energy sources, for example, hydro, nuclear, and fossil fuel prime movers, then each kWh produced and used in this region would be modeled as an "average kWh," produced from 1/3 hydro, 1/3 nuclear, and 1/3 fossil fuel. This is the approach taken in attributional LCA modeling.

An evolution is taking place within the field of Life Cycle Assessment, away from models of "average" systems that support retrospective analyses, towards models of "marginal" systems that support prospective analyses. In contrast to attributional LCAs, prospective LCAs explicitly attempt to characterize what the impacts will be of potential decisions. Thus, they are designed *to provide insight about "what will happen if we decide A or B," rather than "which product is to blame for which burdens." The processes whose levels of output will be impacted by a decision or a change in demand are referred to as the "marginal" processes – those producing "at the margin."*

At first blush, the marginal modeling underlying prospective LCA may appear more complex or data-intensive than the average modeling underlying attributional LCA. In practice, this is not necessarily the case, and in fact prospective LCA helps take some of the arbitrariness out of thorny LCI modeling issues such as allocation (Weidema 2001). In most if not all cases, the use of LCA for decision support appears to call for adopting the prospective approach as far as possible.

A number of inter-related questions arise in attempting to identify how the energy supply system actually responds to changes in demand, depending upon characteristics of the demand change including its location, timing, duration, and magnitude. In order to provide a sound basis for prospective modeling of the electricity supply system, we must address the following questions:

- *What do we know about how the electricity supply system responds to changes in demand?*
- *How is this system's response to demand currently modeled, by what models and with what accuracy?*
- *How should LCA incorporate these understandings and perhaps the results of these models in its treatment of electricity?*

Respondents recognize this as a critical issue that needs resolution. They agree that the choice is crucial and can significantly affect the results of an LCA.

The purpose or use of electricity data in an LCA is also crucial to the issue of average and marginal modeling. The purpose of electricity data can be grouped in to one of two categories:

1. Conducting an LCA of an energy system (e.g., power plant, distribution system)
2. Conducting an LCA of a product/process (i.e., electricity data is a system input)

The European LCI terminology of "background LCI data" and "foreground LCI data" can also be related to the two cases above. In the first case, electricity LCI data would be considered "foreground LCI data" because it is directly affected by decisions based on the study. Where as the second case represents electricity LCI data as "background LCI data" because it is not directly affected by decisions based on the study, other than the quantity of material inputted into the foreground system. The distinction between the purpose of electricity data in an LCA is key to many

> In the *Journal of LCA*, The SETAC-Eur Workgroup on Data Availability defines marginal as: short term (variation in demand in a short term, calculated with no change of the production facility) or long term (increase or decrease of the electricity consumption on a long term, calculated with possible to change of the production facility). And if anyone can interpret this for me, I will be grateful.

discussions concerning the use and appropriateness of average and marginal modeling techniques.

Responses to the question of average versus marginal modeling can be broadly grouped into three types of responses:

1. Applicability of average and marginal modeling of energy systems based on the scope and purpose of an LCA
2. Effect of average and marginal modeling on estimating uncertainty in LCI data
3. Appropriateness (or lack their of) accounting for marginal changes in "background" LCI data that would result from a product/process under consideration.

Each topic is summarized below.

<u>Average –vs- Marginal Topic #1: Applicability of average and marginal modeling of energy systems based on the scope and purpose of an LCA.</u>

The applicability of using average or marginal modeling for electricity data is dependant on the purpose and scope of the LCA. Based on comments received from the respondents, the selection is not always clear but the following should be considered.

<u>The purpose or use of the electricity data; Background or Foreground LCI data.</u>
"Where electricity supply falls into the foreground system, a marginal approach will always be warranted, whereas an average approach will often be sufficient where electricity supply falls into the background system."

<u>The scope of the LCA; short, mid, or long-term (e.g., days, months, years, etc.).</u>
"Ideally a marginal approach is preferable in order to reflect 'real' conditions, they also expressed doubt that detailed data, such as specific hourly information, is relevant for LCA's, and that annual averages are straight-forward and sufficient. Most of the short-term and also mid-term changes in the electricity source profile have a regular pattern, so that a reasonable averaging should be used. In national/regional average LCIs, annual variability should be sufficient as the variability between the technological systems is likely to dominate the overall uncertainty/variability. For product-type LCA's, modeling complex behaviors goes beyond the scope of LCA."

"There may be instances where long-term marginal data is relevant. For example, an LCA of a device that operates only at a specific time of day, week or season, will need to factor in long-term marginal data for this specific energy supply, i.e. to distinguish peak electricity as a separate product."

<u>The overall impact of the electricity contribution to the LCA results.</u>
"Often in electricity production, older technologies are used (i.e brought on-line) to supplement mainstream power production during times of high demand. This is more cost effective than increasing the production capacity by building new facilities.

Unless a decision is a huge electricity consumer, a marginal approach may be less clear since a given site at which a life cycle decision is to be made, may not be supplied now or in the future by one electricity source. The marginal or prospective approach is actually more complex (than the actual calculation of a hypothetical marginal MJ) because the assumptions are less rigorous or certain. Will the marginal MJ be from electricity technology source A or maybe B? With deregulation and new/non-traditional generation and the generally long construction/permitting times, the marginal source may not even occur before an actual life cycle decision has been made and then remade."

Q1: Agree or Disagree with the respondents?
Q2: Are marginal data that add detail to the inventory worth the cost?
Q3: How has electricity data been historically modeled?
Q4: How are life cycle decisions actually affecting electricity use at the site or at the product use sites; is it increasing use or decreasing?
Q5: Are refinements from adopting a marginal approach (as compared to the average) providing improvements in accuracy that are less than the errors elsewhere in a system under analysis?

Average –vs- Marginal Topic #2: Effect of average and marginal modeling on estimating uncertainty in LCI data.

The general consensus of the respondents indicated that marginal modeling provides the ability to quantitatively estimate the uncertainty in LCI data, were as with average modeling (specifically in the prospective case) uncertainty can only be best estimated qualitatively with little premise. Therefore, to best justify the uncertainty in the results of an LCA, marginal modeling would be the preferred approach. The following respondent excerpts are provided to add context (and opposition) to this conclusion as it relates with stochastic (probability) modeling approaches commonly used in LCA's of energy systems.

"Changes in the source profile can be incorporated by modeling short-, mid- and long-term scenarios, where these can reflect changes in fuels and technologies (i.e. changes in the grid mix for the average LCIs, and changes within the particular technology for the marginal LCIs). Importantly, the stochastic (probability) models recommended to include process variability should also include data uncertainty, i.e. the input probability distributions should include uncertainty due to variability, as well as that due to the nature of the data (e.g. uncertainty in the quality of future fuel sources). In this way, the uncertainty associated with the future scenarios can be quantitatively reflected in the inventory, i.e. the fact that the long-term scenario has much higher uncertainty than the short- and mid-term scenarios can be reflected. Although estimating the uncertainty associated with the data is inherently subjective, there are methods which mitigate this to some degree (Weidema and Wesnæs, 1996), and even a subjective estimate of uncertainty is preferable to representing a highly uncertain future inventory with false accuracy, as a mid-point LCI or a stochastic model only incorporating variability would."

"Stochastic modeling approaches can be used to incorporate variability, i.e. the inventory is presented as a range of probable output rather than a single mid-point. However, to be meaningful, stochastic models need to be applied to the actual process models underlying the inventory, where the actual variability in the data samples can be incorporated, and correlations between inputs can be avoided by modeling the causal mechanisms."

"A further point regarding incorporating data uncertainty and variability in the LCI using stochastic modeling is that this may force a marginal approach, or at least, force the definition of more tightly defined average systems. This is because incorporating the variability within systems averaging widely different processes can result in such high uncertainty (i.e. such a wide range in the output) that no significant differences are discernable between options in a comparative assessment"

"The marginal approach has its advantages and disadvantages. While the uncertainty of the system being modeled is inherently lower (both in terms of its avoidance of using average data and its avoidance of arbitrary allocation rules), the necessary data is not always readily available. Furthermore, companies are more comfortable publishing LCI information as national or product wide averages to protect confidentiality. The uncertainty of the average approach could be improved by the use of improved reporting along regional rather than national averages, or broad technology types, etc. This would allow a more informed determination of whether electricity supply can appropriately be kept in the background system (i.e. the contribution to uncertainty of the electricity LCI needs to be evaluated in light of the overall inventory uncertainty)."

Q1: Agree or Disagree with the respondents?
Q2: Does marginal modeling decrease the uncertainty in LCI results, or only improve the transparency of the degree of uncertainty?
Q3: Is the level of detail as stochastic modeling necessary for "background" and/or "foreground" electricity LCI data?
Q4: What is an acceptable level of uncertainty in both "background" and "foreground" electricity LCI data?

Average –vs- Marginal Topic #3: Appropriateness (or lack their of) accounting for marginal changes in "background" LCI data that would result from a product/process under consideration.

When conducting an LCA (especially a prospective LCA) of a product/process, the implementation or use of the product or process in question can effect the background electricity LCI data, especially if the product or process consumes a significant amount of energy in relation to the local energy grid. Responses to this topic were varied and mixed based on the appropriateness of including these changes (i.e., assessing a product/process with the associated environmental impacts) and the additional effort to account for them correctly.

The following example was given to demonstrate this view:

"Consider the theoretical case where a steel company wants to construct an electric arc furnace for re-melting of steel scrap. Such an industrial plant can require several hundred GWh per year of base-load electricity. An LCA is performed to investigate the environmental implications of locating the plant in different countries. Based on the ethical rule that good systems should be supported, the LCA practitioner decides to use average data for Norwegian electricity production in the study. This is based, to more than 99%, on hydropower. However, the electricity in Norway, Sweden, Denmark, and Finland is freely traded on a common Nordic market. Except for grid losses, the consequences of using electricity in Norway are essentially the same as using electricity in Denmark or Finland. If the investment is made in Norway, more electricity will be used within that country and less Norwegian electricity will be available in the other Nordic countries. Despite the large electricity demand of the plant, the start-up of a new electric arc furnace in Norway would still have a marginal effect, and no more, on the production of base-load electricity in the Nordic countries. The electricity production that is affected by a marginal change in the base-load demand is, in the short run, based on coal combustion. Hence, the short-run consequence of locating the plant in Norway is that more electricity is produced in coal-power plants."

As another respondent stated, "Advantages of the marginal (prospective) approach is that it can reduce data collection efforts substantially (since only data for the marginal production is needed, not data for the entire system), and it avoids arbitrariness in setting of system boundaries, notably in relation to geographical and technological boundaries as well as in relation to co-product allocation. The average (attributional) approach may be warranted when seeking to allocate blame for past activities. The marginal (prospective) approach is warranted when analysing the consequences of a decision, i.e. as a decision-support. The marginal approach can also be applied to allocate blame for past activities by using historical data valid at the time of the decision that led to the situation that you wish to allocate blame for."

"If we know the electricity supplier in a life cycle process, we try to find out the electricity generation mix (percentage hard coal based generation, nuclear, hydro etc.) of this supplier. If that is impossible, we use the average generation mix per year of the country or the region (IEA Statistics). We use today's mix for both historical and future processes. Our attitude is that a summation of LCA study results of every system should not extremely exceed the actual environmental impact. You should not burden one electricity needing system for the fact that marginal electricity generation is needed in an electricity generation system to secure deliveries to all consumers."

Q1: Agree or Disagree with the respondents?
Q2: Can we identify regional grid mixes? And are these appropriate for LCA? For what purpose?
Q3: Is it appropriate to account for environmental impacts (changes in LCI data) resulting from background changes in electricity supply as a result of a the product/process under review?

Boundaries for the Electricity Generation Systems

LCAs attempt to approximate comprehensive treatment of the environmental, health and resource burdens associated with product systems. In theory, this comprehensiveness entails inclusion of "all significant" burdens (e.g., pollution releases, resource consumption flows, or other impacts) of "all" causally-connected processes. Thus, the system boundary for a life cycle inventory model requires a series of choices along two dimensions: environment and supply chain. In the case of a life cycle inventory database concerning the electricity supply system, we note the following boundary decisions which must be made:

- *Which environmental flows and other data needed for impact modeling should be tracked, how, and with what specificity, for processes in the electricity supply system? How should the cut-off criteria be determined?*
- *Which activities and operations along the supply chain should be included? That is, how wide and how broad should the system boundaries been drawn? (e.g., should capital equipment be included? transport of workers to the production sites? service sector inputs such as from designers, lawyers, accountants, advertising, etc.?)*

Decisions related to establishing specific cut-off criteria to set boundaries for particular processes in the system under study are properly left to the goal and scope definition portions of individual life cycle assessments, or to the protocol development phase of the LCI database projects. This workshop will seek to pool insights from prior and current LCAs of electricity systems concerning the broader boundary questions of what sorts of flows and what sorts of processes are important to retain in general when modeling the electricity supply system.

This workgroup will address the multiple 'what is in, what is out?" sorts of questions, which are fundamental to life cycle inventory analysis. The workgroup will address its topics in a pair of sequential sessions.

The first session on boundaries will address environmental emissions and releases. Key questions include:

- *Based on prior LCA and non-LCA environmental evaluations of the electricity supply system, is there a set of air emissions for which reporting in LCI databases should be required? Is it possible to define a recommended set of air emissions that would be sufficient to include in databases? What are the principal data sources for the key air emissions, and are there important differences among them from country to country?*
- *Water releases – the same set of questions as posed above for air emissions.*
- *Additional releases (e.g., radioactive isotopes) – the same set of questions.*
- *Other impacts (e.g., thermal enrichment of water, land use, etc.) – the same set of questions.*

A second work session will address setting the system boundaries which will be used to determine which mass and energy flows will be accounted for. Key questions include:

- *What inputs besides fuels are essential/important to include for different types of generation?*
- *How have input/output-based LCA analyses been used in the past to shed light on this question, and what have their findings been?*
- *What is the significance and suggested treatment of maintenance and repair inputs?*
- *What is the significance and suggested treatment of supporting infrastructure?*

Respondents comments can be divided into two categories: Environmental Flows and Activities & Operations. Relevant excerpts are provided below for context.

Environmental Flows

"Of course, the interventions to be considered are constrained by the data availability (the degree of development/demonstration of the technology, and the scope of the study), however, a default list of interventions towards which to strive would certainly be helpful. This would also be very useful in standardizing the use of aggregate interventions, e.g. TSP, TDS. Water-related interventions where found to be particularly problematic when trying to compare across different LCIs, e.g. use of categories such as "sulfates", "nitrates" etc., rather than individual components."

"Also requiring standardization is how energy resources are defined in fossil fuel-burning systems. This is required because different systems may burn very different quality fuels."

"It would be valuable to know other significant inputs, such as water, chemicals for the treatment of water, and inputs related to repair/maintenance. At that point, one can decide what to report. In addition, these other inventory parameters must be highly transparent."

"The European ExternE project on External Costs of Energy (as well as the joint US/EC Study on Fuel Cycle Externalities, which was a forerunner of ExternE) started with a screening of a range of pollutants and related impacts. Based on expert judgement (no formal selection procedure), a set of some priority impacts and related pollutants were identified. External costs (as an aggregated damage indicator) were very much dominated by greenhouse gases, NO_x, SO_2, and particles (and related secondary substances, namely ozone, sulfates and nitrates). This conclusion was quite robust. Although the small number of key substances was often criticized for being inappropriate, other LCA studies for energy technologies with a more comprehensive inventory are also dominated by the same set of pollutants."

"The picture will change with an increasing share of renewables, but the above mentioned pollutants still dominate LCA results for renewables technologies because of the importance of the conventional energy supply mix."

"Non-stack emissions should not be overlooked (e.g. dust from blasting during mining, and blown from waste dumps). The impacts associated with solid waste management in coal-fired systems are typically poorly assessed. Diffuse sources of water pollution (as distinct from pipe-discharges) are often overlooked. These include surface run-off from waste dumps and stockpiles, and water collecting in open cast mining pits. Leachate from waste dumps and stockpiles, as well as seepage from ash dams and pollution containment dams are similarly neglected, although their significance can be considerable."

"Local scale impacts on ecosystem via land use, alteration of water systems etc. partly are the dominant impacts for decentralized renewable energy technologies. In past LCA's,the methodology does not treat land use adequately in LCA and is limited in addressing such very local scale impacts. While recent developments explore the feasibility of site and time dependent LCA, a key problem of local scale impacts is that it is not necessarily the technical characteristics of a facility, but much more the specific environmental conditions at a given site (soil quality, water regime, topography, ...) which determines the level of impact resulting from a 'unit' of environmental intervention. Technical parameters on the one hand and site specific environmental conditions on the other hand are very closely interrelated and cannot be evaluated independently any more. Summing up environmental interventions to an aggregated indicator is therefore very difficult, if not impossible."

"If LCI/LCA data should be used in a labelling scheme for green electricity, I recommend to additionally include local criteria which cannot be considered in standard LCAs. This is successfully done within the "naturemade star" label for environmentally excellent electricity from renewable sources (see http://www.naturemade.org). It covers aspects like river ecosystems, agricultural techniques, visual impacts of wind power plants, etc."

"An adequate treatment of direct ecosystem impairment caused by hydroelectric power production, coal, oil and uranium extraction is still missing. Nuclear waste disposal is another issue where an adequate assessment within LCA is still missing. Noise seems to get more attention in connection with wind power. Also here, broadly accepted inventory parameters and impact assessment methods are still missing."

"For hydroelectric power plants, care must be taken not to neglect methane emissions if substantial amounts of biomass have been drowned by the artificial lake."

"Pollution from electricity supply systems may occur in the very far future (e.g. long-term radionuclide releases from abandoned uranium milling sites). How shall such emissions be treated? How should we treat the treatment and disposal of radioactive wastes? How should discounting be applied in LCI of electricity systems (positive, zero, negative discount rate)?"

Q1: Is a list of environmental flows, and other data needed for LCA, already available?
Q2: Where should the boundaries be drawn for electricity generation with respect to environmental flows?
Q3: What is the most commonly accepted system of nomenclature for environmental flows?

Activities and Operations

The SETAC Workgroup on Data Availability stated that "Good LCA data on energy production comprise data on extraction, refining, transport and storage of fuels, electricity production, distribution and consumption. The construction and demolition of power plants, as well as processing and recycling of fuel wastes, are all part of an LCA for electricity production. For nuclear, hydro, wind, and solar power the production of the equipment/facility has the largest impact in the environment."

It seemed that not all respondents understood what was meant by infrastructure support. However, one comment addressed capital equipment, transport of workers to the site, research and administrative divisions, etc., saying these areas should be explicitly addressed when defining system boundaries.

"Catalysts and especially precious metals are important due to the high environmental loads per gram. Capital equipment is (obviously) relevant for new renewables such as photovoltaics and wind power but also for hydroelectric power plants."

Q: In a product LCA, are infrastucture support activities negligible?

New and Non-Traditional Electricity Generation

As mentioned in the introduction, the electricity supply system is dynamic, with old technologies being slowly replaced by new. As interest in minimizing the environmental impacts of electricity generation increases, so will the ongoing development and evaluation of innovative electricity supply technologies. One arena of potentially influential use of LCAs of energy systems may be in environmentally evaluating and comparing new generation technologies. Characterizing them for LCA poses a whole new and different set of data and modeling issues.

There are at least three inter-related sets of issues involving LCAs of new and non-traditional generation. The first is simply how to model the new technologies in LCA. For new technologies that simply replace other point source generation facilities, this may not be a challenge. But how shall LCA characterize distributed generation, from the average perspective and from the marginal perspective?

The second set of issues relates to comparative evaluation of the new technologies, such as fuel cells, from the LCA perspective. LCA evaluations of nascent electrical generation technologies may inform policy and/or research prioritization among competing options. How can LCAs be performed in a consistent, holistic, and valid fashion for these systems, which are marked by high degrees of uncertainty and technological volatility, as well as scarcity of data?

The third set of issues relates to the way in which LCAs of product life cycles will tend to treat new generation, and potentially to influence the demand for new capacity. The treatment of in-place capacity will probably need to be considered separately from the treatment of demand that drives new capacity. An example concerns the proper treatment of flow-limited renewable *energy, such as wind power capacity in place. From a prospective point of view, no change in product demand (whether increase or decrease) will change the amount of electricity generated by wind power capacity in place – its output is fixed by nature. So how, if at all, should this wind capacity appear in the results of a prospective LCA?*

Due to issues such as deregulation, distributed generation, environmental pressures and regulations coming into force in the short term, expected rise in fossil fuel, population growth and a threat of global climate impact, we are tackling the electricity issue at a time that it is far from a stationary target. In addition to looking at how electricity is being made now, we should also look at how it will be made in the coming years. This puts a different spin on it and what and how data may need to be gathered.

Respondents expressed the following views:

"Many countries are setting goals to increase the use of renewable energy sources. For example, Germany aims at a share of 50% electricity from renewable energy sources by 2050, resulting in a drastic change in their energy system. Current LCAs for emerging technologies however most often use the current electricity mix as an input to upstream processes. Besides the obvious strive for getting the best available data for the relevant new materials (using tools like technical learning curves, etc.), it is important to use the characteristics of a future energy system with an adequate share of renewable energy as an input to basic processes in order to provide a more realistic picture of the emissions resulting from energy supply. It is of course not easy to agree on a specific future energy scenario, so the door is open for another source of potential differences between LCA studies. Relevant excerpts from respondents are provided below for context."

"The major opportunity is to establish the life cycle inventory with all inputs that track along the supply chain back to natural resources. Transparent descriptions of boundaries and possible multiple outputs should be made. The intersection with a current electricity power grid (either measured as average or marginal) is likely to be a secondary life cycle issue. These new electricity sources have already been studied in several life cycle reports."

"Boundaries for the inventories for new technologies must be consistent and include activities such as transmission and distribution and agricultural activities. The inventories of point source generation facilities must be inclusive so that they can be compared on a consistent basis to distributed sources."

"The need to include a quantitative consideration of uncertainty is critical here. It is essential to guard against the comparison of incomplete systems, i.e. incomplete inventories. A comparison using incomplete or inconsistent data sets is likely to be more misleading than useful. Qualitative LCA methods (such as Graedel's Streamlined LCA approach) may be of more value than quantitative methods here."

"The application of attributional LCIs to new technologies should not be a problem, as long as it is recognized that materials of construction, life-times and use patterns will play a larger role in the analysis than for conventional energy technologies. For prospective LCIs, perhaps these could be viewed as incremental changes approached through discrete steps rather than load changes?"

"If we want to compare specific energy technologies to evaluate their potential for solving specific environmental problems, it is sufficient to look at the impacts normalized to a kWh at the power plant's gate. If we want to take into account the capacity effect and a given supply task, we might take into account a back-up technology. I would prefer however to look at the full energy system with a certain share of renewables, which again requires the use of an energy system model."

"There is uncertainty about new technologies and how to model them; that is true. There may be equal uncertainty about the existing collection of grandfathered power plants if we look to a future with the things mentioned above. I do not believe we can take a snapshot of "NOW" in the electricity sector and use it even if it is a lot more convenient. To me, this illustrates the need for the workshop to air out these issues at the Macro end."

"Energy is just about never generated from natural resources to use where most people live (Iceland may be the big exception). Coal and oil are shipped large distances; so is electricity. If something is "closer", it probably costs less and probably requires less energy loss to get to the user AND maybe less of an impact. The cost and impacts of transportation should be addressed. The same goes for wind, solar, wave, biomass, and even geothermal."

"The correct treatment of flow-limited sources such as wind or hydroelectric power refers to the question about the relation between the macro- and microeconomic situations. To my understanding, LCA is a tool which helps to allocate scarce environmental resources and scarce "pollution rights" among competing products (like the price system is used to efficiently allocate the scarce traditional production factors human power, capital and land). Hence, macro-economic limitations like the ones mentioned should not have an influence on the way the LCA is carried out."

Again, it was pointed out that the "correct" way of modelling new generating technologies depends on the goal of the LCA. Do we need a dynamic model to assess the environmental impacts of (the introduction of) new technologies in order to answer the question whether these technologies should be favoured or not? Or, would it be sufficient to model a possible future (steady) state (when the technology is more or less established)?

Q1: Can LCA's be conducted on new technologies for which production data are not available?

Q2: Is there a need to develop a common future energy scenario that considers renewable and distributed energy sources for use in prospective LCA's?

Q3: How should distributed generation be accounted for in National or Regional energy grid data?

Transmission and Distribution

The transmission and distribution infrastructure component of the electricity supply system has traditionally been accounted for in LCA in terms of the expected average line losses, or loss of power due to electrical resistance in the system connecting the point of generation to the point of use. The amount of this loss depends on the length of the transmission, the voltage at which transmission occurs, the size of the conductor, and the manner in which electricity is transmitted. Common losses range between two to five percent of power being transmitted (EIRRG 1998). LCA researchers from Asian Pacific countries have identified additional issues associated with what might be termed "fugitive losses" of electric power, which is un-metered or un-identified electricity consumption.

In fact, there may be important reasons other than line power losses to include the transmission and distribution network within the scope of LCAs of the electricity supply system – namely, the environmental impacts of constructing, maintaining, and operating the systems themselves. Some environmental concerns raised in connection with electricity transmission and distribution lines include visual impacts, habitat impacts, noise (from high-voltage and ultra-high-voltage transmission), and others (e.g., any remaining concern about effects of electrical and magnetic fields?).

This work group will address both the energy losses associated with transmission and distribution, as well as the impacts of T&D infrastructure itself.

Transparency was raised as an important factor in this area. The inclusion of traditional transmission losses should be made transparent. An inventory table should include the notes regarding whether or not transmission losses are included and what percentage loss was actually used. It was reported that on the low voltage level (380V), losses more than 10% are not unusual. On higher voltage levels, losses are much lower (below a few percents). Additionally power switching stations (SF_6-losses) and operation of high voltage transmission lines (N_2O-emissions) are important. Also, illegal losses should be analyzed, but in places, the magnitude of this is still unclear. Relevant excerpts from respondents are provided below for context.

"The existence of significant transmission system infrastructure effects leading to environmental emissions is really unclear. Such effects are more likely to be the focus of separate studies."

"T&D relates to impacts that are expected to be important within the scope of actual life cycle assessments. For example, South Africa has a problem with bird mortality when eagles insist on nesting on the pylons. Other considerations include habitat loss, and herbicides used in maintaining land. Also, we should not forget the emissions of SF_6 in power switching units and the production of N_2O of high voltage power lines."

Q1: Agree or Disagree with the respondents comments?
Q2: Can losses from T&D process be accounted for confidence (i.e., the level of uncertainty does not invalidate the use of the results)?
Q3: What types of environmental interventions should be considered when modeling T&D systems?

Co-Products and Allocation

Co-product allocation arises as an issue whenever a process produces more than one useful product. For example, steam turbine systems may sell both electricity and low pressure steam as useful products. When co-products are present, modelers must determine how much of the burdens associated with operating and supplying the multi-output process should be allocated to each co-product. Modelers must also decide on how to allocate environmental burden across co-products when one is a waste stream that can be sold for other uses.

The ISO standards for LCA, particularly ISO 14041 related to inventory analysis, provide methodological guidance on this issue. But they call for practitioners to attempt to avoid allocation if possible; and secondly, to attempt modeling approaches which reflect the physical realities (i.e. mass basis) of the process in terms of how inputs and releases would be altered if the levels of output were altered for one or more co-products. In summary, proper application of the ISO guidelines on allocation requires a physical understanding of the co-product production processes.

The workgroup on co-products and allocation for the electricity supply sector could provide considerable value to the worldwide LCA community by providing clarity and consensus on allocation rules. It could also help by pointing to the data sources which characterize the geographic details of which plants and plant types in which regions are producing how much of the economically valued co-products. Such information will assist in assessing transportation distances for other LCAs which include the use of these co-products.

The SETAC Workgroup on Data Availability stated that "In many cases energy has a big influence on the results of LCA, which is the main reason why allocation methods must be chosen and reported carefully. The chosen allocation method has to be transparent and suited to the purpose of the study… The allocation methods that can be applied are the energy, exergy and price method. In the working group report these methods are briefly discussed. The main methods for allocation used today seem to be either the exergy or the energy method."

Some respondents simply stated that allocation should be performed following ISO 14041.

ISO 14041 requires the following procedure be used for allocation in multifunction processes:

- Allocation should be avoided, wherever possible, either through division of the multifunction process into sub-processes, and collection of separate data for each sub-process, or through expansion of the systems investigated until the same functions are delivered by all systems compared.
- Where allocation cannot be avoided, the allocation should reflect the physical relationships between the environmental burdens and the functions, i.e., how the burdens are changed by quantitative changes in the functions delivered by the system.
- Where such physical causal relationships alone cannot be used as the basis for allocation, the allocation should reflect other relationships between the environmental burdens and the functions.

For allocation in open-loop recycling, ISO 14041 recommends the same procedure but allows a few additional options. If the recycling does not cause a change in the inherent properties of the material, the allocation may be avoided through calculating the environmental burdens as if the material was recycled back into the same product. Otherwise, the allocation can be based on physical properties, economic value, or the number of subsequent uses of the recycled material. The international standard does not include information on the effect of the different methods on the life cycle modeling, for example the feasibility of the methods, the amount of work required, or what type of information that results from the application of the methods.

The following comments regarding allocation highlight alternatives to the ISO 14001 guidance.

"Allocation problems can rarely be eliminated through subdivision. When it is possible, it is an adequate procedure if decisions based on the LCA results has a significant effect on the internally used function(s) but a small effect on the production volume of exported functions. In other cases, it is too time-consuming and/or does not result in accurate and comprehensive information about the environmental consequences of our actions. This conclusion is clearly an adjustment compared to ISO 14041.

An allocation problem can be avoided through system expansion as long as there is an alternative way of generating the exported functions and data can be obtained for this alternative production. It is an adequate way of dealing with allocation when an action will affect an exported function, if the data uncertainties are not too large, and if the indirect effects are important enough to be significant for a decision. This conclusion is different compared to the recommendations in ISO 14041. The application of system expansion gives accurate results only when it is based on accurate data on the effects on the production of exported functions and on the indirect effects of changes in the exported functions. In many case studies so far, the system expansion has been based on inaccurate data or assumptions.

Allocation based on physical, causal relationships is possible for multifunction processes where the functions are physically independent of each other, if the internally used function is marginally affected or if the environmental burdens can be represented by a linear and homogeneous, mathematical function of the functions produced. It is an adequate allocation method if decisions based on the LCA results have a significant effect on the internally used function(s) but a small effect on the production volume of exported functions. In other cases, it is too time-consuming and/or does not result in accurate and comprehensive information about the environmental consequences of our actions.

System expansion, subdivision and allocation based on physical, causal relationships apparently have a potential for providing accurate information on the consequences of our actions. However, further research is required to realize this potential. Other allocation procedures presented in ISO 14041 do not result in information about the consequences of our actions. Hence, they should be applied only when a more accurate approach does not provide information that is significant for any decision that may be based on, or inspired by, the LCA results.

In the light of these conclusions, the following, revised recommendations, are proposed if the purpose of LCA is to increase our ability to anticipate the environmental consequences of our actions:

- When the choice of allocation approach is expected not to be important for any decision which is based on, or inspired by, the LCA results: we recommend that the most easily applicable allocation method be used.

- When the allocation can be important for a decision, but the possible effects on the production of exported functions are expected not to be important: we recommend that allocation be avoided through subdivision, that allocation be based on the physical, causal relationships between the functions and environmental burdens, or that an adequate approximation thereof be used.
- When the production volume of internally used and exported functions are proportional and effects on the production of exported functions can be important for a decision, but the indirect effects of a change in the production of exported functions are expected not to be important: we recommend that all of the environmental burdens of the multifunction process be allocated to the product investigated.
- When the indirect effects can be important for a decision: use system expansion or an adequate approximation thereof.

A conclusion from our analysis is that when the production volume of the different functions cannot be independently changed, system expansion, or an approximation thereof, is the only approach that gives comprehensive information of the environmental consequences of our actions. When the effects on the exported functions can be significant, but the uncertainties regarding the indirect effects are very large, the LCA practitioner should either develop different scenarios for the indirect effects, or clearly state that a course of action may have important but unknown indirect effects on other life cycles."

"Allocation remains a requirement of a LCI and thus a clear picture of the byproduct or co-product is needed. While the actual use of byproduct is often an economic decision, a LCI can reflect a whole range of potential use. Again, a transparent description is essential. For example, the North Carolina State University uses a mass basis and then tries to break down processes into enough detail so that the emergence of a co-product is clear and can be allocated (the micro-allocation approach)."

"The marginal approach of allocating avoided or additional burdens, only, appears the most meaningful for prospective LCIs of energy systems." The following case study illustrates the benefits of this allocation procedure.

> No allocation problem regarding the electricity product was encountered within coal-fired electricity production in South Africa (since no steam or heat is sold as a co-product). However a different allocation problem arises due to the modern South African power stations being designed to burn near discard-quality coal. Allocating burdens to the coal-fuel supplying the station is found to be very significant for those stations supplied by dual-producing collieries, which produce a high-quality export coal (requiring significant coal preparation), as well as a low-quality power station coal. This can be regarded as combined production, so can be modeled by a marginal analysis (keeping the production of one product fixed, by varying the other). For some stations, this combined production is made more interesting by the fact that the power station coal is made up of a blend of run-of-mine coal and discard (the waste product from export-quality coal preparation). The combined production is therefore able to reduce the mass of discard waste (the disposal of which has significant environmental impacts), as well as avoid the waste of energy resources discard coal represents. The "avoided" burdens approach is used here, where the power-station coal is "credited" with the avoided burdens of discard disposal.

> Very significant for the electricity profile is that the discard-fuel source is essentially burden-free, i.e. is not allocated any mining burdens other than the "avoided" burdens."

"In attributional LCA, a co-product is defined as one that contributes to the income of the producer. This definition can also be used in prospective LCA, although here there is no need for a sharp definition of co-products, since all outputs to technosphere, whether co-products or waste for treatment, can be modelled in the same way."

With respect to forecasting future co-product allocations in a prospective LCA, "future market potential for co-products can be assessed by the use of forecasting, as when collecting data for any other future process."

The following discussion provides an overview of the lessons learned and approach used by the European Commissions ExternE project (purpose is to determine the externalities associated with fuel cycles). The allocation of impacts were discussed in detail for a combined heat and power plant between the electricity and heat output.

"In the ExternE project the following allocation alternatives were discussed:

- Allocation based on operational characteristics (operation is heat or electricity oriented ➔ electricity or heat as by-product ➔ benefits of joint production are assigned to the by-product. We can also use the ratio of additional fuel input required for producing the "by-product" to the total fuel input required for both electricity and heat production.)

- Allocation based on thermodynamic parameters (energy or exergy content; several other parameters are discussed in the literature, taking into account various characteristics of the steam-process, but results achieved with these parameters generally are within the range covered by the energy content and the exergy indicators)

- Allocation based on the final product's price (Assuming a perfect market, the final product's price probably is the best indicator for the utility of the product. However, the price of electricity and heat is highly dependent on the customers demand characteristics and other non-technical parameters.)

As an example, the table below shows external costs (as an aggregated indicator of environmental impacts) for heat and electricity from a 520 MW coal fired CHP plant in Germany for different allocation rules:

	mEuro/kWh$_{el}$	MEuro/MJ
Credit for heat, substituting		
oil fired domestic boilers	2.7	
gas fired domestic boilers	5.0	
Credit for electricity		(- 7.8)
Additional fuel input	4.9	0.13
Energy content	2.3	0.64
Exergy	4.6	0.24
Price	3.6	0.38

(note that these numbers are taken from a 1996 ExternE report. External costs in this example are not based on the most recent ExternE methodology, but they still give a good indication on the effect of different allocation rules)

In ExternE, it was decided to report results based on exergy-allocation as mandatory, and in addition (optional) results based on energy content or price allocation to reflect specific conditions under which the CHP plant might be operated.

"Current market values are delicate without considering the development of the overall markets. However, I do not see too many difficulties here, except maybe power plants burning blast furnace and coke oven gases.

Suggested co-products:

- coal: electricity, heat, gypsum (building industry), fly ash (cement production)
- oil: electricity, heat, gypsum
- natural gas: electricity, heat
- coke oven gas: disposal of "residual gas" of coke production, electricity, heat
- blast furnace gas: disposal of "residual gas" of iron melting, electricity, heat
- nuclear power: electricity, heat
- hydroelectric power plant: electricity, flood protection, irrigation, recreation, fishing
- photovoltaics: electricity, weather protection (if integrated in slope roofs, façades)
- combined heat and power units (motors, fuel cells): electricity, heat
- biomass: electricity, heat
- waste incineration: treated wastes, heat, electricity, slags (cement industry)
- biogas from manure: treated manure, heat, electricity
- biogas from organic waste: compost, heat, electricity
- biogas from sewage sludge treatment: conditioned sludge, heat, electricity

- geothermal power plant: electricity, heat, therapeutic baths (e.g., the Blue Lagoon, Iceland)

General comment: in many cases, heat is not used but emitted to air and water.

Q1: Is there is a general rule or approach for allocation that is acceptable for all parties involved and applicable for all situations? ISO 14001?
Q2: If not for all situations, which method of allocations is best suited for energy systems, and why?
Q3: Is there an accepted practice for determining when to include or exclude a co-product (mass, energy, exergy, etc.)?

Other Issues – Transportation

According to the SETAC Workgroup on Data Availability, a good understanding of the technical aspects of transportation systems is necessary to enable the proper use of LCA data for transport. Inventory data for transport systems should be based upon a life cycle perspective. The final use of fuels in transportation is much more important than oil extraction and fuel production. In the final use the most important parameters are fuel consumption and the loading factor. Variation in energy intensity per km is caused by the choice of transportation, i.e. ship, rail, road, or air, and traffic congestion: fuel production (extraction, transport, refining, storage, transport), transportation (engine type, fuel type, exhaust gas cleaning) and transport performance (vehicle type/size, load, return trip, traffic conditions).

Waste Management

A good understanding of waste management is necessary to enable the proper use of LCA data for waste treatment. Inventory data for waste should also be based on a life cycle perspective. This means that emissions and resources from transportation and waste treatment are included and described separately. Waste treatment is a complex chain of processes. The structure of the chain depends on the waste source, country, waste treatment, transportation, etc. Providing a simple guideline for data availability and quality for waste is difficult. There are various good publications and case studies from different countries available on the web (see www-address of EPA, ERRA and EU). These can be used as good information sources for models for LCA waste data. Also a lot of information can be found in the proceedings of the international workshop organized on LCA and treatment of solid waste (AFR-report 98, Swedish Environmental Protection Agency). Environmental authorities in different countries have also produced similar data sets.

Waste management can be subdivided into three waste modules: waste generation (municipal, trading, construction, industrial, regulated), waste collection, and waste treatment (landfill, biological/decomposition, incineration, recycling).

Conclusions

The goal on consensus of modeling electricity supply is really a long-term issue. At the workshop, we need to limit our sights to describing how an average or representative profile should be created The availability of worldwide data is a smaller issue as there many data sources now available that are useful for electricity LCI profiles.

The first step is to develop a smaller core of parameters that are technically clear and generally of environmental interest. These parameters can meet the immediate needs of credible information. Then a series of second and third rounds of information development can be undertaken.

Bibliography

Tomas Ekvall, Sverker Molander, and Anne-Marie Tillman, “Marginal or Average Data – Ethical Implications,” printed in the proceedings of *1st Int. Conf. Life Cycle Management*, Copenhagen, August 2001, pp. 91-93.

Tomas Ekvall, Sverker Molander, and Anne-Marie Tillman, ”Normative Moral Philosophy and Methodology for Life Cycle Assessment,” prepared for the workshop, October 2001.

Tomas Ekvall, “ System Expansion and Allocation in Life Cycle Assessment: With Implications for Wastepaper Management,” PhD thesis, Chalmers University of Technology, Gothenburg, Sweden, 1999.

Tomas Ekvall and Göran Finnveden, ”Allocation in ISO 14041 - A Critical Review,” Printed in *Journal of Cleaner Production*, Vol. 9 (2001), pp.197-208.

Rolf Frischknecht, “Allocation in Life Cycle Inventory Analysis for Joint Production,” *J. of LCA*, 5(2), pp 1-11, 2000.

Rolf Frischknecht,, “Chapter 5: LCA for Decision-Making: The Advantages of Marginal Considerations,” PhD thesis, Swiss Federal Institute of Technology (ETH), Zurich, Switzerland, 1998.

Peter Michaelis, “Life Cycle Assessment of Energy Systems,” paper prepared for the Royal Commission Environmental Pollution Study on Energy and the Environment, March 1998 (http://www.rcep.org.uk/studies/energy/98-6067/michaelis.html)

Response to Review Comments
February 28, 2002

Tom Tramm

As I indicated in my voicemail, the report looks great. Attached are a few nit-picky suggestions. Please call for more detail or other examples.

Section 2.1 - Marginal vs. Average

When are attributional and consequential LCI each appropriate?

Paragraphs 2 and 5 incorporate an example involving cement made of fly ash and clinker. We may have used this example in our discussions, but it doesn't look right in print. It would be more realistic if it referred to concrete made from fly ash and Portland Cement. Fly ash is used to replace Portland Cement in concrete mixtures, usually on a one-for-one basis. Clinker often refers to bottom ash that would not normally be used in concrete production although it does have value in other applications.

Response: Reword paragraphs 2 & 5 as follows:

The rules used to define which processes are in or out of the system in attributional modeling are those based on an observation of how materials and energy are flowing in the system at the given point in time. For example, if ~~cement~~ concrete is made with 1 kg fly ash and ~~2 kg clinker~~ 1 kg Portland Cement per unit of ~~cement~~ concrete output, then the LCI model will show these flows into and out of the ~~cement~~ concrete manufacturing process.

The rules used to define which processes are in or out of the system in consequential modeling are those based on an estimation of how material and energy flows will change as a result of the potential decisions or disturbances. In the fly ash example, if the output of fly ash is constrained – namely, if it is fixed based on the demand for electricity – then increases in the demand for high-fly-ash-~~cement~~ concrete will not in the short run change the output fly ash. Instead, it would increase the output of ~~cement~~ concrete made 100% from ~~clinke~~r Portland Cement. The consequential LCI model would attempt to take such output constraints explicitly into account.

Characterizing the Response of the Electric Utility System to Demand Changes

Paragraphs 2 and 3 (Facts 1 and 2) are a little too precise. In both cases there are exceptions that were discussed and ought to be acknowledged, even if they are probably insignificant to LCA results.

For example, hydro plants drawing from impoundments are often dispatched to meet daily peaks rather than base-loaded. Limited water supply means that there are only so many kilowatt-hours available per year from a dam but you can usually have the power any time you want it. Hydro units respond more reliably than more complex generating options, so they are scheduled to come on to meet the daily peaks or address local environmental concerns. Every system has special cases like these but they would not affect LCA results.

The sentence in paragraph 2 would be more accurate if it said: "… output responses typically occur at plants…."   Since the exceptions are inconsequential, we should not be obliged to discuss them in this report.

Paragraph 3 talks about capacity additions being the ones that will be the most profitable. There are enough other factors in these decisions that maximizing profitability is seldom possible. For instance, siting considerations usually preclude the most profitable plants. Some plants will be added to assure reliable power supply in specific areas. Wind turbines and solar panels will be installed to help satisfy a relatively small demand for renewable energy. It is enough to recognize that only profitable plants will be built.   Too many considerations are involved in these decisions to make a simple statement.

Paragraph 3 would be more accurate if it read: "In the long term, the type of new capacity added is generally the one which is estimated to satisfy the given load shape at the lowest overall cost." This characterization is historically more accurate and will be more palatable to representatives of state public utility commissions.

Response: Replace this section as follows:

Some members of the breakout group were familiar with realities of how the electricity system (at least in the US) currently responds to changes in demand. Others were familiar with responses of electricity systems in Europe. From their input, the following general facts were captured:

1) In the short term, output responses <u>typically </u>occur at plants which have the highest variable cost among those operating at the time of the demand change.

2) In the long term, the type of new capacity added is <u>generally</u> the one which is estimated (by investment decision makers~~) to be the most profitable for the given load shape~~ <u>to satisfy the given load shape at the lowest overall cost</u>.

3) The future is irreducibly uncertain, while the electricity supply system is dynamic and evolving. Thus, there are important levels of irreducible uncertainty concerning how the electricity supply system will respond to demand changes, even if we used the most sophisticated models available.

Section 2.2 - Boundaries and Flows

<u>Boundaries</u>

The first paragraph cites the "high-lift used to load the coal into the feed hopper at the utility plant" as an example of a component that is not part of the dedicated infrastructure. We need to use a stronger example. In most cases, coal-handling equipment has no other function and should really be counted as part of the dedicated infrastructure. However, the cranes used to erect the coal-handling equipment, boilers, etc. are usually used at many construction sites. The example should be changed to something like "cranes used to erect the boilers and other plant structures."

Response: Replace this example as follows:

The participants evaluated which activities and operations along the supply chain/life-cycle should be included for energy supply systems. Particularly, they discussed what should be included (e.g., should capital equipment be included? transportation of workers to the production sites? service sector inputs such as from designers, lawyers, accountants, advertising, etc.?). The consensus was to include infrastructure for only dedicated resources. For example, the material used to construct a boiler used in a coal-fired utility plant should be included, but the materials used to construct the ~~high-lift used to load the coal into the feed hopper at the utility plant~~ cranes that are used to erect boilers and other plant structures would not be included. Likewise, impacts from workers traveling to and from work should be excluded. This is not a hard-and-fast rule, but more a general rule-of-thumb to be used in drawing boundaries for energy supply systems. The potential impact from infrastructure operations should always be evaluated, even on a cursory level, to support their exclusion with confidence.

Benoit Maurice

I find your document really good and have add some comments on 2 paragraphs: Characterizing the Response of the Electric Utility System to Demand Changes and Environmental Flows

Under "Characterizing the Response of the Electric Utility System to Demand Changes," add the following:
1) Compare to others products like steel or car, electricity has a specific characteristic: it cannot be stocked : at any moment, production must be equal to the sum of consumption and transmissions losses. Every day, the load shape has big variations, due to specific use like light for example. To produce electricity, utilities should have different power plants which are able to adapt their production to the consumption, this means to produce electricity as base load, (e.g nuclear energy), semi-base-load (e.g coal, gas, fuel power plant..) and peak load (e.g. gas turbine). This element has to be taken into account when one try to characterize the response of the electric utility system to demand changes. A « base load use » or a « peak load use » will not have the same answer. To characterize the production, LCA practitioners should use rather than simple arguments, model developed for electricity planning which integrate most of the time such parameters.

Response: Add a new paragraph at the end of the section, as follows:

In addition, it is noted that in contrast with many other products, electricity has the specific characteristic that it cannot be stocked directly. At any moment, production must be equal the sum of consumption and transmissions losses. Throughout the day, the load shape varies greatly due to increasing and decreasing use, such as lighting at night. To produce electricity, utilities typically have different power plants which are able to adapt their production to the consumption, producing electricity as base load, (e.g., nuclear energy), semi-base-load (e.g., coal, gas, fuel power plant) and peak load (e.g., gas turbine). This element has to be taken into account when one tried to characterize the response of the electric utility system to demand changes. A "base load use" or a "peak load use" will not have the same answer. Rather than using simple assumptions to characterize electricity production, LCA practitioners should model for electricity planning which allows for the integration of such parameters.

Under Environmental Flows, add the following flows « As, Ni, and Pb » to air emissions. These substances are widely study in different research programs.

Concerning water emissions, the list is too long : I would limit the metal emissions to Pb and Hg. BOD (5,7,10) is certainly also too much. Most of the time, BOD 5 is only available. Furthermore, BOD like COD are indicators of water quality rather than a real flow.

Most of the time, limitation on temperature depend of the temperature of the river: for example, administration may authorize to emit water with a delta of temperature of 8°C to temperature of the river. Then the temperature of emission of water change from summer to winter.

Response: Change Exhibit 2 as follows:

Exhibit 2. "Minimum" List of Environmental Flows for Energy Supply Systems

Resources	***Air Emission***	***Water Emissions***
Water (location & type)	CO_2	Chemical oxygen demand (COD)*
Fuel (in ground)	CO	TDS
Minerals (in ground)	PM (10, 2.5)	Total suspended solids (TSS)
Biomass (harvested)	CH_4	Biological oxygen demand (BOD) (5, 7, 10)*
Land use (area & location)	SO_X	Flow
	NO_X	Temperature change,** or thermal loading in energy units
Wastes	NH_3	NH_3 (as N)
Solid waste	Hg, Pb	Total Kjeldahl nitrogen (TKN) (as N)
Radioactive Waste (H, M, L)	VOC (NM)	NO_3, NO_2 (as N)
Hazardous Waste	Dioxin	Polycyclic aromatic hydrocarbons (PAH's)
	PAHs	Phosphates (as P)
Other Releases	SF6	Cu, Ni, As, Cd, Cr, Pb, Hg
radionuclides	HFCs	

* COD and BOD are indicators of water quality rather than flows

** Limitation on temperature depends on the temperature of the river

Concerning the comment on the number of water emissions, lack of availability as the sole basis for this comment is not enough to make the change. More discussion on this point may be needed.

<u>Bev Saur and Bill Franklin</u>

We have reviewed the workshop summary document and made some comments and suggested revisions (see attached document). Overall we found it to be a good summary of the activities and outcomes of the workshop. We feel very strongly, however, that the strong link between the purpose of the workshop and the work plan for the US LCI database (DB) project must not be overlooked.

As you are certainly aware through your participation in the advisory committee to the US LCI DB project, much of the work on characterizing US electricity generation, transmission, and distribution (at least for traditional generating technologies and some of the better established emerging technologies such as wind and solar) has already been identified as a top priority for the database project. It would be most efficient and provide the most benefit to potential users if efforts to develop LCI data for electricity generation are done in collaboration with the US LCI DB project rather than independently.

For non-traditional technologies such as fuel cells that are not significant contributors to national grids, NREL is most likely the organization with the best knowledge of NNT technologies and would be the best source of data. These data may not initially be included in the US LCI DB project; however, we would recommend using the US LCI DB protocol where possible in developing NNT data so that they are compatible for future incorporation in the database. Similarly, other areas that are of interest to the electricity industry, such as the response of the system to daily and seasonal dynamics in supply and demand, but of lesser usefulness to the US LCI DB project, may be appropriate to evaluate independently, again using the US LCI DB protocol. Incidentally, the Protocol was reviewed independently by Patrick Hofstetter and others.

We feel that it is imperative to avoid the duplication of effort and potential incompatibilities in methodology, data format, etc. that would inevitably result from independent efforts to develop LCI electricity data. The US LCI DB project already has the commitment and support of DOE, the Navy, GSA, and private industry, and NREL has established and is maintaining the website for dissemination of information on the US LCI DB project. Independent efforts to develop LCI electricity data would be detrimental to the success and usefulness of the US LCI DB.

Perhaps it would be useful for the next steps section of the report to include a reference to the US LCI DB project because it is now moving into Phase II and the number one priority is the fuels and energy database development. For your information I am sending that section of the NREL report, which is now at NREL for review and will very shortly
be forwarded to full advisory committee for comments.

Bev and Bill attached the draft document with comments, which are summarized here:

1. Insert "life cycle" before inventory in the Abstract.

Response: Accept change.

2. Delete "life" before LCI (redundant) on page 1.

Response: Accept change.

3. Delete an excess space and insert a missing quotation mark on page 2.

Response: Accept change.

4. Insert "who" before "were unable to attend." on page 3.

Response: Accept change.

5. Additional wording on page 5: *Marginal disturbances or perturbations* are infinitesimal disturbances; e.g., installing one new end-use that causes an incremental increase in demand for electricity.

Response: Accept change.

6. Two changes on page 7:
   Correct misspelling of "been" to "be" and
   Invert "for only" to read "The consensus was to include infrastructure only for dedicated resources."

Response: Accept change.

7. Change "process" to "processes" on page 8.

Response: Accept change.

8. Page 9: Exclusion of these environmental flows should raise concern ~~towards~~ about the comprehensiveness of the LCI data set, and
   under Exhibit 2: (comment: may want to define some terms such as PAH's, TKN, etc.)

Response: Accept change.

9. Page 10: "Practitioners must also decide ~~on~~ how to allocate environmental burden across co-products when one is a waste stream that can be sold for other uses."
   Change i.e. to e.g.: (e.g., mass basis)

Response: Accept change; also omitted the reference to "mass basis" which in fact ISO explicitly does not call for.

10. Heading for section 2.4 – insert (NNT).

Response: Accept change.

11. Page 12: Reword sentence to: "For example, because operating emissions may be very low or essentially zero, the predominant source of emissions associated with the generating technology may be construction emissions, which are problematic to allocate ~~allocating construction emissions~~ over the functional unit of kWh ~~is problematic~~."

Response: Accept change.

12. Page 12: "For a large penetration into the grid, LCA practitioners must take into account that DGs do not produce point-source emissions as do large central generators." What type of emissions do they produce? "Additionally, depending on the reason for a DG installation, the functional unit may not be kWh." Example would be helpful.

Response: The intent of the statement was to say DG's are more spread out geographically than large, point-source generators. The paragraph was rewritten as follows:

The drivers for distributed generation are the demand for reliable power, the desire to avoid down-time costs, and the mitigation of significant up-front capital expenditures for large generators and transmission and distribution infrastructure. Distributed generators (DGs) are typically small, and may use fossil or renewable fuels. For a large penetration into the grid, LCA practitioners may take account, during impact assessment, of the fact that emission source locations are distributed over a large geographic region as well. Additionally, depending on the reason for a DG installation, the functional unit may not be kWh.

13. Page 13: If you ~~do~~ can assemble life cycle inventory data for a technology.

Response: Accept change.

14. Page 14, "discussion~~s~~ points"

Response: Accept change.

- The workgroup on Boundaries created a first cut at ~~listing~~ a "minimum" list of environmental emissions that should be included in the inventory.

- The workgroup on New & Non-Traditional Technologies noted that, despite difficulties that arise in conducting LCAs on renewable generating technologies, due to uncertain operating data, any database on electricity must be flexible enough to include ~~different~~ non-conventional stressors, e.g. bird kills, land use.

Response: Accept change, except land use was omitted here since its inclusion is becoming conventional.

Rolf Frischknecht

2.1 attributional vs consequential:
The third recommendation might be described more precisely as it depends on the time scale on which the 1kWh change occurs (short term, long-term, very long-term). I attach an extract of my thesis where I elaborate the use of consequential models in decision situations.

Response: Changes were made throughout this section to reflect the reviewer's comments.

2.2 Boundaries:
I am not very happy with the "minimum list" as already stated in the plenary session. Radionuclide emissions from NPP, reprocessing plants and uranium mines should be added to the minimum list. Electricity is NOT a resource (but a product like many others as well). SF6 is missing as an important pollutant in electricity distributing systems. HFCs are missing although important in cooling equipment for underground coal mines.

Response: Radionuclides, SF6 and HFCs were added to the table. Also, electricity was omitted since this is a list of flows to/from the environment, not flows from other processes in the technosphere.

2.3 allocation
There was nearly any discussion about the usefulness of a distinction in allocation procedures between a consequential and an attributional approach. I doubt whether such a distinction is necessary and meaningful. I attach a paper published in the Int.J.LCA which covers exactly this topic and where I describe a managerial economics-oriented approach to allocation illustrated with combined heat and power production.

I would appreciate it very much if you could include the two references attached into the document:

Frischknecht R., 1998. "Life Cycle Inventory Analysis for Decision-Making; Scope-dependent Inventory System Models and Context-specific Joint Product Allocation: Section 5. LCA for Decision-Making: The Advantage of Marginal Consideration." Excerpt (pp. 47-79) from PhD. Thesis Nr. 12599, Swiss Federal Institute of Technology (ETH), Zürich

Frischknecht R., 2000. "Allocation in Life Cycle Inventory Analysis for Joint Production," in Int J of LCA 5(2), pp 1-111.

Response: These references are included in the website created for the workshop, as well.

<u>Philippa Notten</u>

I appreciate my comments come too late, but just in case it may be of use/interest to you, I have attached the summary of what I saw as the important points of the Marginal vs Average group's discussion that I drew up for Jim Petrie (he sponsored my participation at the workshop).

My only problem with the report write-up is that I don't think the distinction between "Attributional" and "Consequential" is particularly clear, and was sorry not to see the "snappy" definitions we argued out appearing, i.e:

> Attributional: "How are things flowing in the chosen temporal window?"
> Consequential: "How will flows change in response to decisions?"

To my mind, the write-up does not make it clear that these terms were proposed to replace the "marginal" vs "average" distinction of before (i.e. that an attributional approach requires average data and arbitrary rules and boundaries, which the consequential approach avoids).

Another small comment is that I would disagree that the distinction between electricity LCI data for use in other LCIs or for use in comparing electricity generation options is not "particularly interesting, important, or clear." The "consequential" vs "attibutional" discussion is only relevant to the former, since a consequence- or decision-oriented approach is the only valid approach for technology choice studies (but perhaps that is only my opinion). To my mind, of greater interest is the inevitable mix of average and marginal data that creeps in even when a consequential approach is taken, due to the lack of applicable data (however, that we did not get round to discussing).

Attachment:

- Marginal vs. Average

    A significant portion of the group's time was spent on defining what exactly we were discussing. It was agreed that "marginal" was not a good word, as what was actually meant was "focussing on changes or consequences" (be they large or infinitesimal). It was therefore decided that "consequential" LCA was a better term. The discussion slipped from discussing merely the use of average or marginal data, to the framing of the whole LCA problem. The topic was therefore recast as "attributional vs. consequential", which incorporated the wider issues of boundary definition and allocation practices, in addition to the type of data used. Once the terminology had been agreed upon a very large portion of the time went into explaining/defining exactly what was meant by each approach. The following summary statements were (painstakingly) hammered out:

    Attributional: "How are things flowing in the chosen temporal window?"
    Consequential: "How will flows change in response to decisions?"

    Response: Insert a version of Pippa's paragraph in the report to capture the evolution of the discussion. An appropriate place is at the end of the section on "terminology" (page 5), just before the section "When are attributional and consequential LCA each appropriate."

The remainder of Pippa's comments are a summary of the discussion, more than a comment for suggested change.

The key feature of the attributional approach is that it cannot avoid arbitrary rules, e.g. in defining the system boundary (both spatially and temporally), as well as in deciding which processes and environmental interventions to include. A notable difference in the definitions as cast here is that an attributional approach can be used in a prospective LCA (i.e. LCAs using average data are not only applicable in an retrospective or historic sense). The consequential approach on the other hand avoids a rule-based approach by focussing only on the consequences of the change.

Taking a consequential approach was not well-received by all participants, although strongly supported by a few. It was clear that the tool of LCA is seen by many as a summary statement of environmental performance, rather than as a decision support tool. A rule-based approach (as the attributional approach demands) was generally not seen as a particular problem, as long as a standardised set of procedures (such as laid out in the ISO standards) was followed. Much of the opposition to the consequential approach appeared to stem from the two approaches being understood as completely incompatible approaches. It became clear in discussion that many participants were thinking consequentially without really realising it (i.e. by looking at the difference between two attributional LCAs), and that more "converts" to a consequential approach could be won by focussing on the similarities between the two approaches, rather than giving the impression that everything that one currently undertands about LCA needs to be "thrown out the window" when undertaking a consequential LCA.

An important aside, not fully explored by the group in the time available, was brought up by Tomas Ekvall. He presented some interesting reasons why an attributional approach may sometimes still be more appropriate than a consequential approach, including issues of fairness and communication (see paper, “Marginal or Average Data – Ethical Implications”, available on website).

The bulk of the group discussions thus did not particularly pertain to the electricity sector but rather larger LCA methodological issues. In the final group session the discussions did eventually turn to original topic of electricity data, but discussion got somewhat “bogged down” in explaining electricity demand curves and in trying to determine the marginal technology for US power production. It was agreed that different marginal technologies will be identified depending on the type of load requirement (e.g. peaking or base load demand), and that a short and long term marginal for a change in base load demand needs to be identified. Whilst discussions focussed on the typical daily load curve, it was interesting that Benoit Maurice (EDF) disagreed with the US expert (in the absence of utility people, the sole input was from a consultant to the US energy industry, Tom Tramm). Benoit’s argument was that in France the load curve changed according to season (e.g. the nuclear plants are taken down for servicing during summer), so a simple daily load curve can not be identified. His comments on the complexities in identifying marginals were more or less echoed by Caroline Setterwall (from Vattenfall, Sweden) in the report-back session discussion.

Discussion around taking an attributional vs. consequential as it pertains to data collection and data quality was briefly raised towards the end of discussions. The important point that average data is inherently of lower quality was finally able to be raised, which could be clearly demonstrated by trying to determine the average US electricity mix (the high degree of inter-linking in the US grid means that a state- or region-based mix is highly arbitrary). Although a strength of the consequential approach is that it minimises data collection (i.e. data is only required for the processes actually affected by the decision), concern was expressed that the amount of “meta-data” required to determine the marginal technologies may be significant.

The only concrete recommendation that could be agreed upon by the group was that any database that is constructed (electricity or otherwise) should be technology orientated (i.e. data should not be averaged over technologies and markets). Such a database format suits both approaches, since for the consequential approach the necessary technology can be selected, whilst for the attributional approach the desired mix/average can be taken. Concern was expressed about data confidentiality (i.e. companies are happier to release data as sector or regional averages).

Greg Keoleian

The report is well written and well-organized. It is very effective in capturing the presentations and group breakout comments.

I have a few specific comments based on my review:

Page 7: "3) Feasibility studies which apply energy system models are needed in order to generate LCI results for a 1 kWh change in demand for different systems."

A 1 kWh change in electricity demand would be lost in the noise for a grid system. The problem is that the variability in the baseline for a grid even at a given time in the day is obviously much greater than 1 kWh. This points to the complexity in the consequential analysis. The addition of a new manufacturing facility, however, might be a more reasonable load size that would show an effect.

Response: Reword this bullet as follows: "3) Feasibility studies which apply energy system models are needed in order to generate LCI results for a ~~1 kWh~~ noticeable change in demand for different systems." Changed to "modest incremental" change.

One challenge with the consequential studies lies with identifying which processes need to be modeled as incremental. For example, if a new natural gas power plant is constructed to supply a new manufacturing plant do we need to model potential incremental changes in steel production since steel is used to construct the plant? Experience can help guide the modeling, but these types of issues need to be addressed.

Response: Since this particular example was not discussed during the workshop, new wording will not be added. The idea being expressed here is captured in the report elsewhere.

P 12
"bird kills versus fossil fuel consumption and climate change" I would recommend dropping versus fossil fuel consumption and climate change because these also apply to renewable systems at least until renewable infrastructure is produced exclusively using renewable energy.

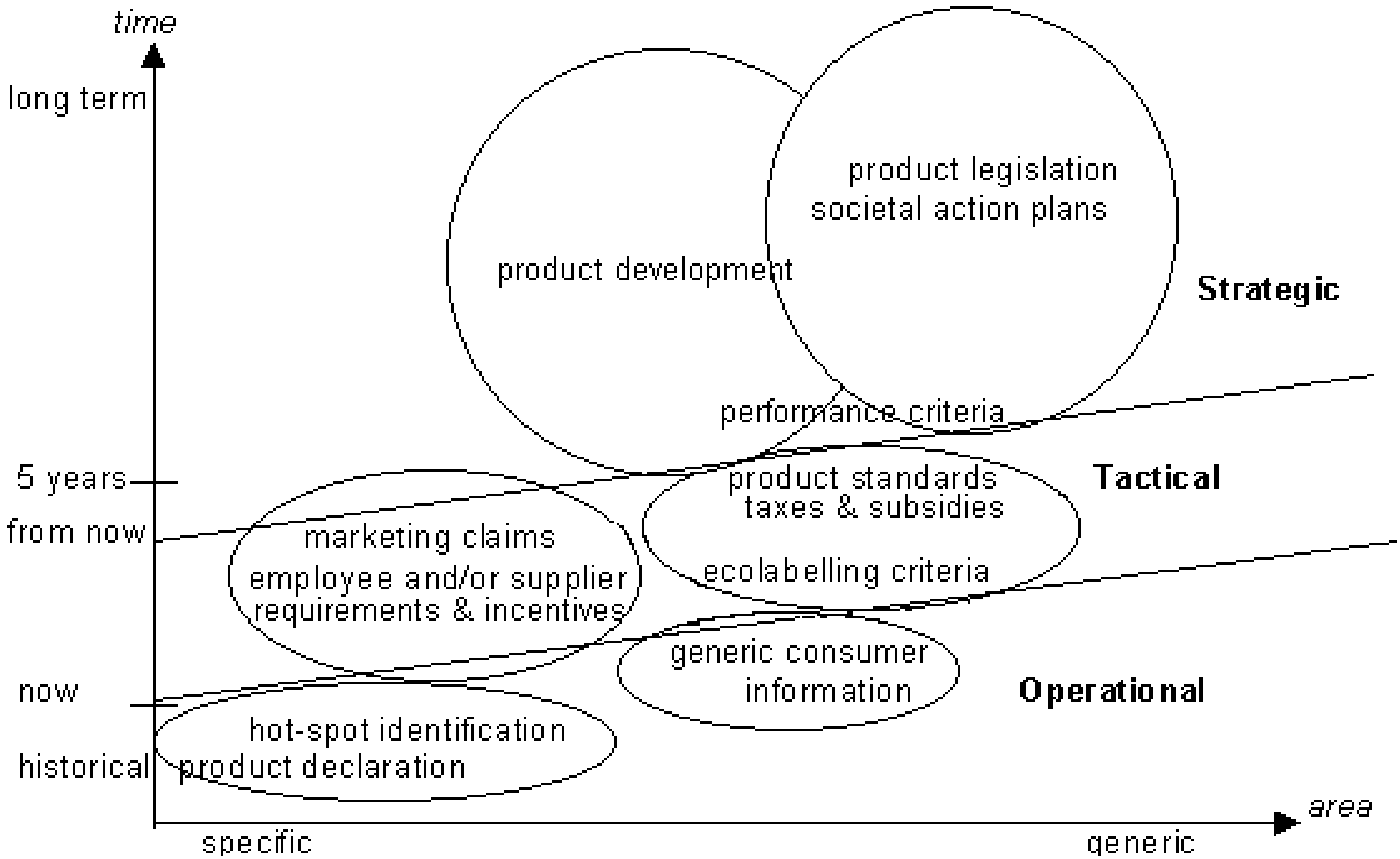
Response: Reword the sentence as follows: "*Additionally, because some impacts can be very different than those from traditional generators (e.g., ~~land use and~~ bird kills ~~versus fossil fuel consumption and climate change~~), the database must be flexible enough to include different stressors.*

Uses and users of electricity LCA information

Bo Weidema

2.-0 LCA consultants

Uses of LCA



time
long term
5 years
from now
now
historical
product development
product legislation
societal action plans
Strategic
performance criteria
product standards
taxes & subsidies
Tactical
marketing claims
employee and/or supplier
requirements & incentives
ecolabelling criteria
generic consumer
information
Operational
hot-spot identification
product declaration
area
specific
generic

Data requirements related to uses

- Attributional LCAs: Statistically representative, historical averages
- Prospective LCAs: Data representative of the processes affected by the studied changes in production volumes

- Tactical applications: Data subdivided by plant, company, geography or technology
- Strategic applications: Data based on modelling, which can explain the causal relationships between inputs and outputs

Asian Electricity LCI database

Atsushi INABA and Masayuki SAGISAKA
Research Center for Life Cycle Assessment,
Advances Industrial Science and Technology (AIST), Japan

0. Asian background data acquisition

For building LCA researchers' network and promoting LCA activities in Asian district, AIST is supporting to implement LCI case studies with financial assistance by the government of Japan. In FY2000, this project has ranched with five countries (Japan, Korea, Malaysia, Thailand, Taiwan; alphabetical order). In this year, expanding member countries to Indonesia, Singapore, Vietnam, the Philippines and Australia, we are compiling the background data for LCA.

The preliminarily acquired data were discussed among the researchers from member countries last year. In this report, only the summary of the results are reported since primitive data have to be revised and upgraded and they must make the readers confused as well as their confidential restriction. We believe these discussing members in Asian region will become key LCA promoters and develop original research activities in this region for the progress of LCA in the world.

1. Japan[1]

Since most industrial processes consume electricity, it is quite important to develop reliable inventory data for electricity. In Japan, 10 electric companies supply electricity to the various regions. There is, however, a problem that only a few figures concerning emissions related to electricity have been reported. So, Matsuno et al. developed process models of power plants for Japanese situation, which simulate the mass flows and estimate the missing figures of emissions dependent on technical parameters of the plants and fuels. Life cycle inventories for the electricity grid mixes of the 10 electric companies in 1997 were developed. Emission of CO2, SO2, NOx, CH4, CO, Non-methane volatile organic compound (NMVOC), dust (all particulates) and heavy metals (Ni, V, As, Cd, Cr, Hg, Pb, Zn) from power stations as well as those from fuel production and transport were investigated. Other pollutants into air, emissions to water, solid wastes, radiation and radioactive emissions from atomic power stations were not included due to limitation of available data.

Direct CO2 emissions related to 1 kWh of electricity distributed by companies ranged from 0.21 to 1.0 kg/kWh (average value: 0.38 kg/kWh). Direct emissions of SO2 and NOx from power stations related to 1 kWh of electricity are 2.5x10-4 and 2.2x10-4 kg/kWh in average, respectively. SO2 emissions calculated in this work were somehow large compared with those reported by electric companies. Detailed information concerning total sulphur content in oil consumed in each oil-fired power station are required for exact calculation of SO_2 emissions from oil-fired power stations. In addition, the ratio of sulphur that goes into slag in combustion must be investigated further. The average amounts of CO, CH_4, NMVOC and dust emissions were 5.0x10-5, 8.2x10-6, 1.8x10-5 and 6.8x10-6 kg/kWh, respectively. Heavy metal emissions from power stations were in the order of 10-9 to 10-8 kg/kWh. Detailed information concerning heavy metal content in oil and coals consumed in fossil fuel power stations are further required for improved assessment of heavy metal emissions. Contribution of fuel production and transport to total CO_2 emission was relatively small. On the other hand, contributions of fuel production and transport to total SO_2 and NOx emissions were relatively large. In the case of CO, NMVOC and dust, emissions in fuel production and transport were predominant to total emissions. Heavy metal emissions into air during production and transport of fuels were in the order of 10-8 to 10-9 kg/kWh.

Table 1 (a) Emissions into air related to 1 kWh of electricity distributed by each Electric Power Company

	CO_2 (10^{-1}kg/kWh)	SO_2 (10^{-4}kg/kWh)	NOx (10^{-4}kg/kWh)	CO (10^{-4}kg/kWh)	Methane (10^{-4}kg/kWh)	NMVOC (10^{-4}kg/kWh)	Dust (10^{-5}kg/kWh)
HOKKAIDO Electric Co.	5.4	11	8.9	1.3	7.6	4.2	9.6
TOHOKU Electric Co.	5.9	6.2	6.6	1.3	9.6	2.1	5.8
TOKYO Electric Co.	3.8	4.6	5.0	1.1	6.2	1.9	3.1
CHUBU Electric Co.	4.6	3.8	4.2	1.1	7.5	2.4	3.4
HOKURIKU Electric Co.	4.8	4.5	5.0	1.1	7.0	2.1	6.1
KANSAI Electric Co.	3.0	3.4	3.9	0.79	4.6	1.9	3.0
CHUGOKU Electric Co.	7.9	5.9	8.7	2.5	12	3.6	7.8
SHIKOKU Electric Co.	4.5	8.0	7.5	1.2	5.4	4.5	5.8
KYUSHU Electric Co.	4.1	3.4	5.2	1.1	5.0	1.1	4.5
OKINAWA Electric Co.	10	22	15	2.3	14	7.6	13
Average of 9 Electric Co.*	4.4	4.7	5.3	1.2	6.8	2.2	4.2

1) Average emissions of HOKKAIDO, TOHOKU, TOKYO, CHUBU, HOKURIKU, KANSAI, CHUGOKU, SHIKOKU, KYUSHU electric companies

Table 1 (b) Emissions into air related to 1 kWh of electricity distributed by each Electric Power Company (continued)

	Ni (10^{-7}kg/kWh)	V (10^{-7}kg/kWh)	As (10^{-9}kg/kWh)	Cd (10^{-9}kg/kWh)	Cr (10^{-8}kg/kWh)	Hg (10^{-9}kg/kWh)	Pb (10^{-8}kg/kWh)	Zn (10^{-8}kg/kWh)
HOKKAIDO Electric Co.	1	1	19	2	2	10	6	9
TOHOKU Electric Co.	0.7	0.9	7	1	0.8	7	2	3
TOKYO Electric Co.	0.8	1	8	1	1	4	3	2
CHUBU Electric Co.	0.9	1	5	1	0.7	4	2	2
HOKURIKU Electric Co.	0.9	0.5	8	0.8	1	7	3	4
KANSAI Electric Co.	0.6	0.9	8	1	1	4	3	3
CHUGOKU Electric Co.	2	0.8	7	1	0.9	8	2	3
SHIKOKU Electric Co.	3	1	8	1	1	5	3	3
KYUSHU Electric Co.	0.4	0.4	8	0.8	1	5	3	3
OKINAWA Electric Co.	4	3	6	1	1	12	2	4
Average of 9 Electric Co.*	0.9	0.9	8	1	1	5	3	3

*) Average emissions of HOKKAIDO, TOHOKU, TOKYO, CHUBU, HOKURIKU, KANSAI, CHUGOKU, SHIKOKU, KYUSHU electric companies

LCI for electricity of Japanese electricity grid mixes in 1998

Recently, Sugita et al. updated LCI for electricity of Japanese grid mixes using the same methodology, based on the statistics of 1998. In his work, effect of electricity exchange between electric companies on LCI was investigated. The results are shown in Tables 1(a) and (b).

2. Taiwan

This study conducts a preliminary analysis of LCI of electricity and compares an existing study in Taiwan. Two sets of inventory data based on the variations of time and methodology are, therefore, constructed or compared. Conclusively, the resource inputs per unit of electricity use are between 2.05 and 2.35 heat content unit. The CO2 emission is about 0.7kg per kWh of electricity use in Taiwan in 1999. Other than the resource inputs and CO2 emissions, the two databases vary significantly. During the period of conducting the investigation, the researchers intend to collect the data of air emission, fly ash production, and nuclear fuel consumption directly from Taipower. For some uncontrollable reasons, these data are not acquired in time. Therefore, some further extensions should be made in spite of the ending of the investigation. With the information compiled for the re-evaluation of constructing the fourth nuclear power plant and the conjunction with a study for a master thesis, the future extension of the investigation appears to be optimistic.

3. Korea

The first preliminary analysis of the electricity production system in Korea from the point of view of LCI was carried out in 1995 using the national average data of the Ministry of Environment (MOE) and the Korea Electric Power Corporation (KEPCO). The Industrial Advancement Administration (IAA) supported the study to identify the inputs and outputs associated with thermal power generation since it has the greatest portion among electricity generation by type in Korea and produces significant amounts of environmental emissions. In addition, a comparison of the environmental characteristics between different fuels used such as anthracite, bituminous coal, oil, diesel, and liquefied natural gas (LNG) has been carried out.

The Korean Energy Management Corporation (KEMCO) expressed interest in developing an LCI database detailing the raw materials use, emissions and solid wastes associated with energy production, delivery, and use in Korea. In 1996, it was decided to conduct a pilot study that would consider power generation at one power plant facility (the MokDong Kangseo District Energy Facility in Seoul). The life cycle inventory with key gross raw material requirements and resulting emissions to produce and deliver 1 TJ of heat and 1 TJ of electricity were obtained, respectively.

During 1996 – 1997, the establishment of a preliminary national database on electricity that included not only thermal power generation but also hydro and nuclear power generation was included in the MOE project. Then, recently, an LCI database to encompass the full Korean electrical energy grid which is a single super-grid covering the whole country with all generators feeding into it and all consumers drawing from it has been developed in a MOCIE LCA project. It is found out that the national average efficiency of production and delivery of electricity in Korea is 36.2%. CO_2 emissions related to 1kWh of electricity which final user can use is around 0.487 kg/f.u. and the contribution of direct emission to total CO_2 is 94%. In the cases of SOx, NOx, and dust the contributions of fuel production and transport are relatively large, 40%, 27%, and 27%.

4. Thailand

Life Cycle Inventory (LCI) for the electricity grid mix in Thailand was developed for the first time. The results of the study were based on data obtained from the Electricity Generating Authority of Thailand and an Independent Power Producer during October 1998 to September 1999, which covered about 85% of total gross domestic electricity generation.

Total CO2, CO, NMVOC, CH4, NOx, N2O, and dust emissions from power plants were 54,527,721 ton, 12,338 ton, 2,601 ton, 1,140 ton, 174,421 ton, 1,705 ton, and 9,005 ton, respectively. Emissions of sulphur dioxide were estimated to have reached 93,161 ton.

Of total carbon dioxide emissions, the amount of emissions from gas-fired power plants was the highest (62%), followed by those from coal (37%) and fuel oil (0.42%). Of total sulphur dioxide emissions, the amount of emissions from coal-fired power plants was the highest (78%) while those from gas-fired power plants were the smallest (9.8%). Of total NOx emissions, the amount of emissions from coal-fired power plants was the highest (53%) while those from fuel-fired power plants were the smallest (2%).

Direct SO2, CO2, and NOx emission intensities from power stations were 1.28x10-03, 0.75, and 2.40x10-03 kg-air pollutants/kWh of electricity consumed by users (kg/kWh) in average, respectively. The average amount of CH4, CO, NMVOC, and particulate emission intensities were 1.57x10-05, 1.70x10-04, 3.58x10-05 and 1.24x10-04 kg/kWh, respectively. The highest SO2, CO2, and NOx emission intensities (related to 1 kWh of electricity consumed by users) were 6.41x10-04, 2.58x10-01, and 1.17x10-03, respectively. The smallest emission intensities of SO2, CO2 and NOx were 1.20x10-08, 1.25x10-05, and 1.40x10-07 kg/kWh of consuming electricity, respectively.

5. Malaysia

Life cycle inventories for the electricity grid mix of electricity generating power stations in Peninsula Malaysia in 1999 were developed. The functional unit investigated was 1 kWh net electricity delivered to consumers in the study area. The scope of the study was limited to the estimation of the emissions of CO2, NOx, SO2, CH4, CO, NMVOC, dust, and heavy metals (Ni, V, As, Cd, Cr, Hg, Pb, Zn).

The preliminary calculated weighted average emissions from the grid per kWh net electricity production in 1999 were 5.6x10-1kg-CO2/kWh, 1.3x10-3kg-SO2/kWh, 6.0x10-4kg-NOx/kWh, 6.6x10-05 kg-CO/kWh, 1.2x10-5kg-CH4/kWh, 3.8x10-5kg-NMVOC/kWh, 4.4x10-5 kg-dust/kWh, 4.6x10-7kg-Ni/kWh, 6.5x10-7kg-V/kWh, 7.6x10-8 kg-As/kWh, 8.3x10-9kg-Cd/kWh, 6.1x10-7kg-Cr/kWh, 4.2x10-9kg-Hg/kWh, 3.8x10-7kg-Pb/kWh and 6.9x10-7 kg-Zn/kWh, respectively. The emission intensities calculated need to be validated and verified with the actual emissions monitoring data for each of the power stations under study. As of the time of investigation, actual emissions data could not be obtained from the relevant authorities. Data verification is critical, as the parameters for estimation of emissions may not reflect the actual situation in Malaysian power stations.

6.Reference

[1] Matsuno Y. and Betz M.; Development of Life Cycle Inventories for Electricity Grid Mixes in Japan, Int. J. LCA, 5 (5) 295-305(2000)

LCI Electricity Data Sources - the situation in Europe

Wolfram Krewitt
DLR, wolfram.krewitt@dlr.de

Rolf Frischknecht
ESU-services, frischknecht@esu-services.ch

US EPA/NREL Int. Workshop on Electricity Data for Life Cycle Inventories

Cincinnati, USA, October 23-25, 2001

the situation in Europe

- very diverse: many countries, many actors (industry, research, public authorities), various technical products, different interests, poor level of harmonization

- the pioneers:
  - Germany: GEMIS 1.0 in 1989
  - Switzerland: EcoInvent 1st ed. in 1994
  - The Scandinavian countries

- jumping on the bandwagon ...

  Germany, Italy, France, ...

Switzerland (I): Ecoinvent 2000, project outline

- Joint effort of LCA-institutes in the ETH-domain and federal authorities (funding agencies)
- Nine institutes work on one central database
- Database on unit process level
- Full transparency and accessibility (fee foreseen)
- Access to database via the web
- Data exchange with relevant software providers such as ecobilan/PWC, ifu/ifeu, PRé

Switzerland (II): Ecoinvent 2000, database content

- Energy supply (PSI, ESU-services)
- Building materials and –processes (EMPA Dübendorf)
- Basic chemicals and plastics (both EMPAs and ETHZ)
- Transport services (ETHZ)
- Waste treatment services (all)
- Graphical Papers (EMPA St.Gallen)
- Detergents (EMPA St. Gallen)
- Agricultural Processes & products (FAL)

Germany: current situation

- **key research institutes developed and use own database systems and software; in general no public access**

- **first database publicly available: Global Emission Model for Integrated Systems (GEMIS); Öko-Institut (version 4.07 July 2001)**
  www.oeko.de/service/gemis/english/index.htm

- **specific competence :**
  - **DLR, System Analysis and Technology Assessment, Inst. of Techn. Thermodynamics: LCI data for fuel cells, solar systems; database: GaBi** www.dlr.de/tt/system
  - **IFEU (Heidelberg): LCI data for biofuels; database: UMBERTO** www.ifeu.de
  - **University of Essen: cumulative energy demand for PV, wind (own database)** www.oeve.uni-essen.de
  - **FfE Munich: cumulative energy demand for fossil systems, heating systems (own database)** www.ffe.de

Germany: Recent developments & upcoming activities

- **Life cycle Inventories of new electricity generation technologies**
  Joint project (DLR, Univ. Essen, FfE, Univ. Stuttgart) funded by the German Federal Ministry of Economics and Technology; (9/2001 - 8/2003)
  Objectives: detailed inventories, common database, public data access

- **'Ecologically optimized' strategies for expanding renewable energies in Germany**
  Joint project (DLR, IFEU, Wupertal Inst.) funded by the German Federal Ministry of Environment; (6/2001 - 12/2003)
  Objectives: LCA of renewables, integration of LCA results into energy scenarios, focus on nature conservation aspects (including hearings with stakeholder groups)

- **Generic database systems with public access:**
  - **German EPA: generic database for environmental management**
    www.umweltbundesamt.de/uba-info-daten/daten/baum/ (only in German)
  - **Federal Ministry of Economics and Technology: pre-study for a generic database**

Italy

- In 1998, the Italian Environmental Agency ANPA commissioned to the Politecnico di Milano an Italian database on energy, transportation and waste management systems
- reviewed database available via internet since February 2001
  www.mirrorsinanet.anpa.it/EcolProd/documenti%20I-LCA
- Linked to EPD activities in Italy: EPD guidelines say that firms making their declarations should use the I-LCA data, if primary data cannot be used
- energy part basically adapts the data of EcoInvent 1996 to Italian conditions

Sweden

- Vattenfall has in the past 3 years worked with LCA on power systems for EPDs (Environmental Product Declarations) according to the Swedish guidelines based on ISO TR 14025. Two third-party certified EPD's, one for hydro power and one for nuclear power http://www.environdec.com/eng/registrations.asp
- LCA activities at Chalmers University (e.g. LCAiT www.lcait.com)

DLR

ESU

the European Commission's activities

- **Environmental and Ecological Life Cycle Inventories for Present and Future Power Systems in Europe (ECLIPSE) (11/2001 - 10/2003)**
  Ambiente Italia (Coord.), ESU, EdF, Vattenfall, Fortum, DLR, KEMA, Univ. Stuttgart
  Objectives: LCI of new decentralised technologies (PV, wind, fuel cells, biomass, small scale CHP); develop an e-database with public access (hosted by ANPA)

- **series of ExternE projects (External costs of energy)**
  running since 1990, strong focus on environmental impact assessment and valuation, country reports from all EU countries available, addressing the relevant major fuel cycles (emissions, impacts, external costs) http://externe.jrc.es/

- **European Energy Data Exchange Network (EDEN) (2/2001 - 7/2002)**
  compile input data and results from energy models (Primes, Poles, Markal, Times)
  emissions covered: CO_2, SO_2, NO_X, particles

Some issues about Electricity LCI database development in Argentina

Laboratorio Ambiente Humano y Vivienda

Alejandro Pablo Arena

Electric sector in Argentina

On the Positive side…

- Argentina started a privatization process of the energy sector in the 90'.
- Today, the generation market is characterized by open and free competition.
- High efficiency, modern natural gas combined cycle power plants displace liquid and solid fossil fueled power plants from dispatching in the market
- As a consequence, current energy production is characterized by lower prices and better environmental performance than in the previous decade.

Main Information sources regarding Electricity Production in Argentina

- **Energy Secretariat: government agency which produces the country's annual energy balance**

- **Most available information in the annual energy balances is published in an aggregated form, which makes the task of calculating energy produced by different fuels and technologies very hard and, in some cases, impossible.**
- **No information about environmental aspects of energy generation is available in the energy balances.**

Alejandro Pablo Arena

Main Information sources regarding Electricity Production in Argentina

- **ENRE: National Electricity Regulation Agency.**

- **Every power plant is enforced to give to ENRE an Environmental Management Plan, together with an Environmental Diagnosis, and the results of the environmental monitoring.**

- **Also a weekly report containing information about events that produced emission levels beyond the legal requirements is produced and delivered to ENRE by every generation agent.**

Main Information sources regarding Electricity Production in Argentina

- **OTHER Institutions:**

- **National Nuclear Energy Commission, etc.**
- **Energy Economics Institute, Fundación Bariloche**
- **Universities**
- **Research Institutions**

Electric sector in Argentina

Challenges…

- There is a lack of cooperation among the involved actors (government, universities, industries).
- The scarce information available is fragmented, information channels are not clear, institutions are weak .
- There are no national emission inventories (public at least).

Alejandro Pablo Arena

Ongoing and projected Electricity LCI database development in Argentina

- There are different publications about the environmental impact of the energy sector, none of them with a LC perspective.
- There are no national emission inventories (public at least), except for the CO_2 emissions.
- There is an ongoing LCI database development project from the Universidad Tecnológica Nacional (Mendoza), but due to the current economic crisis in Argentina there is no funding for the project.

Ongoing and projected Electricity LCI database development in Argentina

- **We're interested in participating in international projects for Electricity LCI database development:**

aparena@lab.cricyt.edu.ar

ORISE

OAK RIDGE INSTITUTE FOR SCIENCE AND EDUCATION

United States Environmental Protection Agency

Boundaries- Which Stressors Need to be Captured in an LCI for Electricity?

Patrick Hofstetter[1,2], [1]ORISE Research Fellow at U.S. EPA, SAB-STD-NRMRL, Cincinnati

[2]Visiting Scientist at Harvard School of Public Health, Boston

International Workshop on Electricity Data for LCI, October 23-25, 2001

Overview

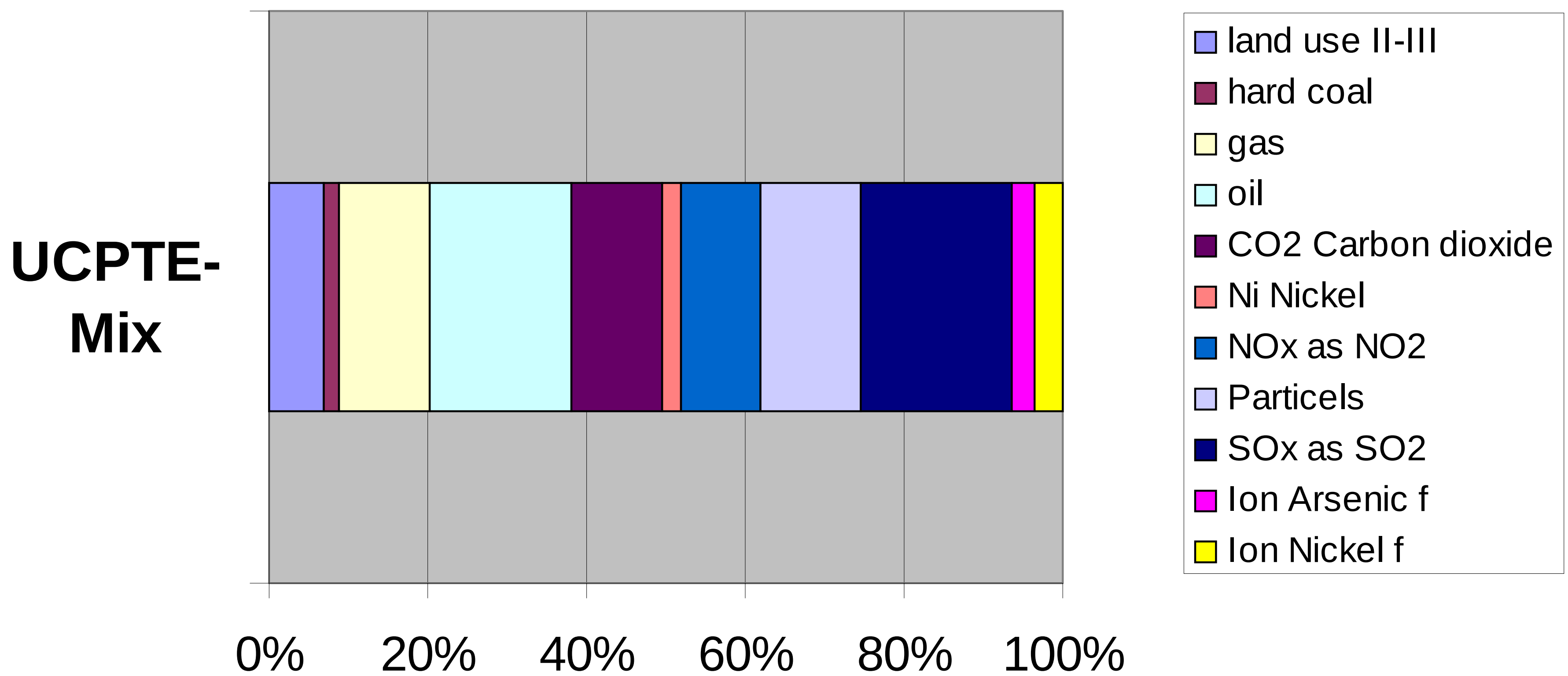
1. **Basic principles**
2. **Available experience**
3. **Flagged impact categories**
4. **Pragmatic approach feasible?**
5. **Summary**

Different interpretations of the meaning of "all effects"

Either: Potential impacts from all uses or releases that are connected with electricity production (=> all elementary flows need to be included)
Or: Stressors that contribute to more than XX% of all impacts measured by impact assessment Y (and Z)

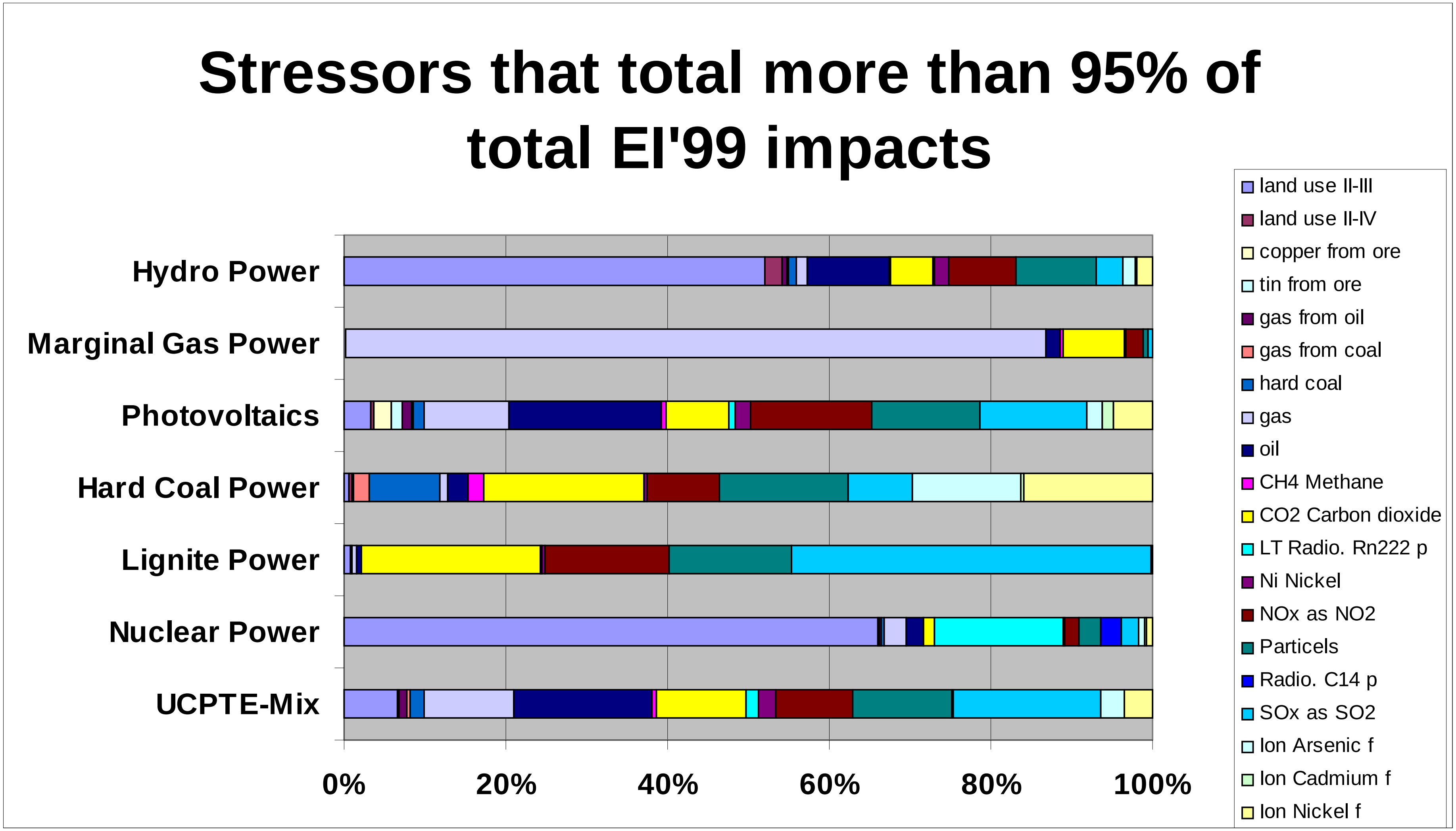
But,
DM's may want to include all environmental impacts that:
-***burden third parties (or own/employers health), or***
-***are not yet compensated (non-market damages), or***
-***are likely to be targeted for eco-taxes, or***
-***pose potential liability problems, or***
-***are most efficiently addressed by LCA rather than other tool***
-***….***

Stressors covering more than 95% of total EI'99 impacts



Assumptions:
- **LCI was "complete" in terms of covered stressors**
- **all stressors that are not captured in Eco-Indicator'99 are unimportant**
- **Eco-Indicators'99 hierarchist's perspective provides the gold standard for damage modeling**

This figure is based on data and tools kindly provided by ESU-Services, Switzerland



Assumptions:

- LCI was “complete” in terms of covered stressors
- all stressors that are not captured in Eco-Indicator’99 are unimportant
- Eco-Indicators’99 hierarchist’s perspective provides the gold standard for damage modeling

This figure is based on data and tools kindly provided by ESU-Services, Switzerland

Flagged impact categories

- land use (partly state of practice)
- ionizing radiation (partly state of practice)
- noise (proposals for road noise impacts)
- water use
- salination
- erosion, soil depletion
- wildlife impacts of dams
- aesthetics
- electro magnetic fields

- accidental releases (e.g., intermediate materials, acute effects, uncommon metabolites)

Guidelines from the SETAC Working Group 'Data availability and data quality'
(Hischier et al. 2001)

Rigid parameter lists for LCIs are not practical; especially, compulsory lists of measurements for all inventories are counterproductive. Instead, practitioners should be obliged to give the rationale for their scientific choice of selected and omitted parameters. The standardized (not; mandatory!) parameter list established by the subgroup can facilitate this.

Proposed self-commitment

SETAC Working Group 'Data availability and data quality' (Hischier et al. 2001)

"Included in the inventory were all parameters that can reasonably be expected to occur in the processes under study, and that can have any environmental relevance, especially when judged with present or foreseeable life cycle impact assessment methods."

A pragmatic approach by Braunschweig (1996)

1. Use readily available use and release data for process at hand. (at least one stressor that may be relevant)
2. Calculate preliminary category indicator scores using impact assessment method(s) that fit(s) goal and scope definition
3. Calculate for all stressors that are assessed within the chosen impact assessment method(s) the necessary release/use rate to contribute more than X% to one indicator score.
4. Use expert judgment, back on the envelope worst-case estimates, data on older processes or similar processes, etc. to decide which stressors are worth the effort to get actual data for.
5. Gather the needed data for those stressors you can most easily get it.
6. Redo steps 2 through 5

Summary

1. LCI for decision support relies on relevant stressors only
2. In most cases only few stressors prove to be relevant
3. Relevance can be defined in many ways and depends on the goal of the study
4. LCIs/databases that shall be used for many different types of decision support lack ONE goal definition

=> How to define “relevant”?

Boundaries, Part 2

EPA Workshop on

LCA of Electricity Supply

Gregory A. Norris, Ph.D.

Sylvatica / Harvard School of Public Health

LCI: 2 Families of Approach

- 1. Process modeling
  - Classical LCA approach
  - Engineering unit processes
  - Material and energy flow emphasis
  - Inter-process flows in physical units
  - Public databases in NA limited
  - High resolution (product output) at expense of boundary (process types & cut-offs)

Process-based example

Comment: sawn oak; source: Boorsma.

Cluster ☐

Allocation and system model

Specific allocation rules

System model id	Comment

Data

INPUTS

Known inputs from nature (resources)

Name	Amount	Unit	Low valu	High valu	Comment
wood	1.573	kg	0	0	

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Low valu	High valu	Comment

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Low valu	High valu	Comment
Electricity UCPTE Hig	0.1778	MJ	0	0	winning.
Truck long-distance B	0.9957	tkm	0	0	475 km full truck, empty truck counted as 1/3 full truck (assumed by PRé): 633 km x 0.001573 tonne = 0.9957 km.tonne
Electricity UCPTE Hig	2.4	MJ	0	0	sawing and other electric processes
Furnace oil B	4.3	MJ	0	0	drying.

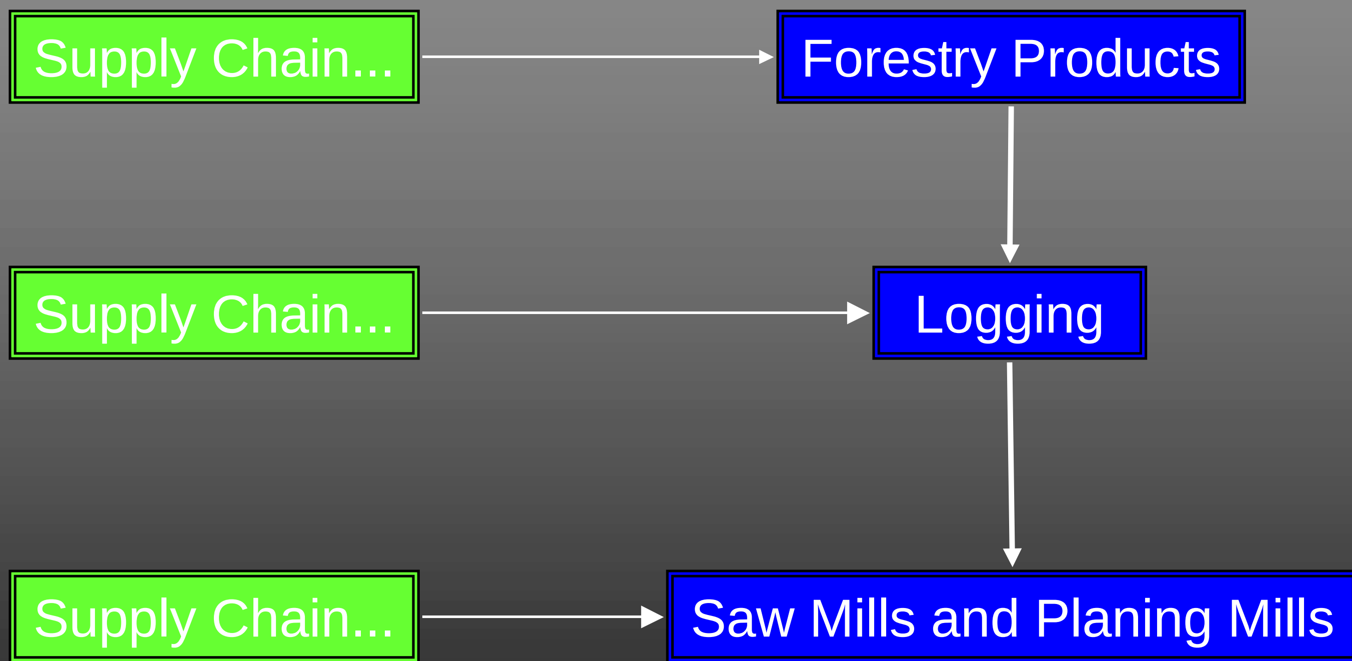
LCI: Second Approach

- 2. Economic Input/Output Approach
  - National I/O model with sector pollution coefficients (kg CO_2 per $ output)
  - Sectors as unit processes
  - Include equipment, services, minor inputs
  - Inter-process flows in dollars (initially)
  - US particularly data-rich (# sectors, TRI)
  - Boundary comprehensiveness at expense of product & process coarseness

US Input/Output Data

- 500 sectors, producing and consuming 500 commodities
- Exhaustive "economic census" ea. 5 yrs
- Annual updates at lower resolution
- Environmental data at sector level
  - Pollution: US EPA
  - Energy consumption: Dept. of Energy
  - Resources: US Geological Survey
- Comprehensive, at expense of coarseness

“Sawn Oak” Example



Inputs to “Saw Mills and Planing Mills”

Input	Value ($)	% of Total
Logging	6689	61.7%
Sawmills and planing mills, general	1274	11.8%
Wholesale trade	621.9	5.7%
Electric services (utilities)	359.2	3.3%
Motor freight transportation and warehousing	245.9	2.3%
Railroads and related services	214.6	2.0%
Banking	110.4	1.0%
Petroleum refining	99.61	0.9%
Gas production and distribution (utilities)	73.31	0.7%
Eating and drinking places	59.91	0.6%
Insurance carriers	55.49	0.5%
Metal stampings, n.e.c.	53.59	0.5%
Automotive rental and leasing, without drivers	53.2	0.5%
Advertising	52.7	0.5%
Management and consulting services, testing and research	48.31	0.4%
Sanitary services, steam supply, and irrigation systems	44.2	0.4%
Industrial inorganic and organic chemicals	36.89	0.3%
Veneer and plywood	35.51	0.3%
Automotive repair shops and services	34.6	0.3%
Adhesives and sealants	33.4	0.3%
Water transportation	33.2	0.3%
Communications, except radio and TV	32	0.3%
Miscellaneous equipment rental and leasing	30.7	0.3%
Legal services	28.3	0.3%
Woodworking machinery	24.4	0.2%
Abrasive products	23.9	0.2%
U.S. Postal Service	21.3	0.2%
Accounting, auditing and bookkeeping, and miscellaneous s	20.81	0.2%
Real estate agents, managers, operators, and lessors	20	0.2%
Fabricated metal products, n.e.c.	19.4	0.2%
Royalties	17.8	0.2%
Industrial and commercial machinery and equipment, n.e.c.	17.61	0.2%
Retail trade, except eating and drinking	17.51	0.2%
Security and commodity brokers	17.2	0.2%
Miscellaneous plastics products, n.e.c.	17.09	0.2%
Colleges, universities, and professional schools	16.39	0.2%
Plastics materials and resins	15.79	0.1%
Paperboard containers and boxes	15.61	0.1%
Screw machine products, bolts, etc.	15.61	0.1%
Paints and allied products	13.71	0.1%
Personnel supply services	13.71	0.1%
Water supply and sewerage systems	12.9	0.1%
Hardware, n.e.c.	12.8	0.1%
Business associations and professional membership organi	12.51	0.1%
Detective and protective services	11.81	0.1%
Engineering, architectural, and surveying services	10.2	0.1%
Air transportation	9.497	0.1%
Lubricating oils and greases	9.103	0.1%
Manifold business forms	8.607	0.1%
Special dies and tools and machine tool accessories	8.299	0.1%
Hand and edge tools, except machine tools and handsaws	7.803	0.1%

Input Boundary Issues

- *Which classes* of inputs?
- How many of the little inputs?

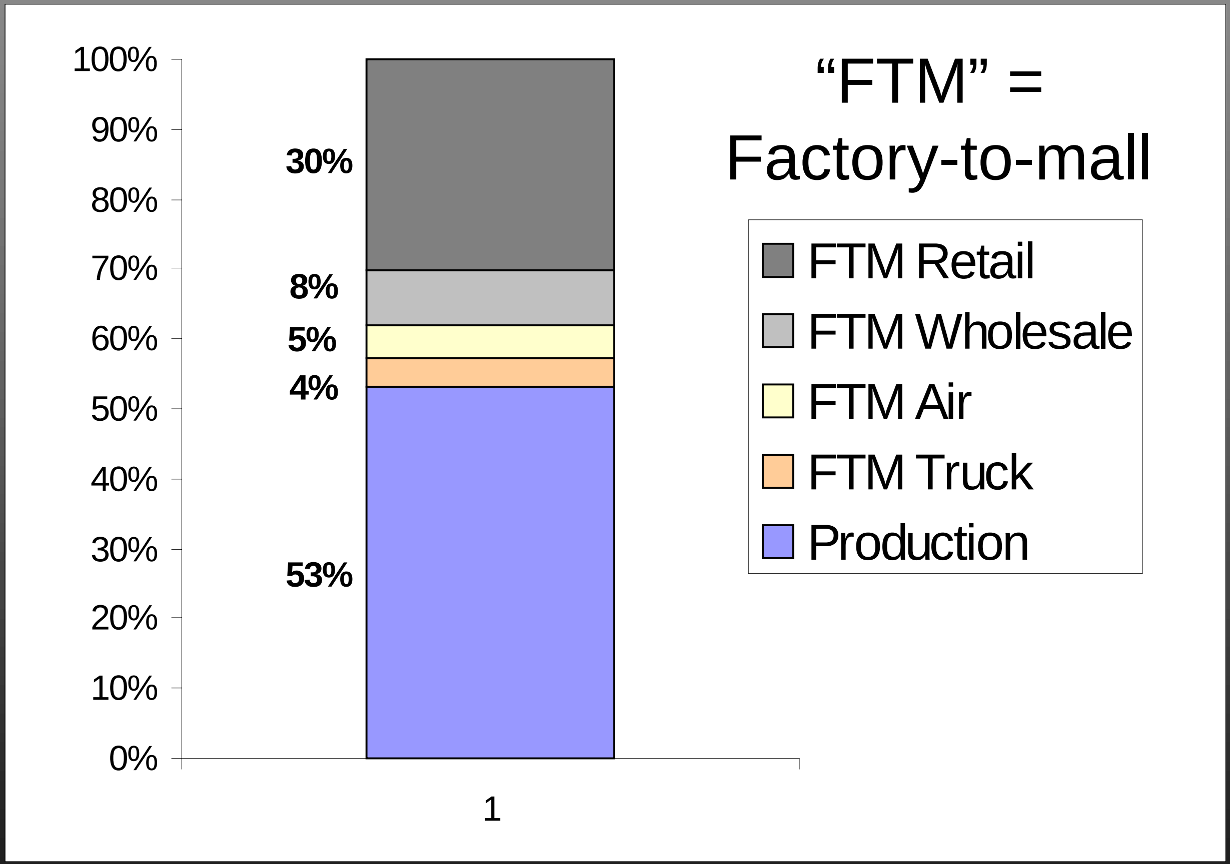
Flexibility in Scope of Input Type

- Material / Energy inputs - major
- Equipment, capital, infrastructure - major
- Material / Energy inputs - minor
- Overhead inputs (building, site, etc.)
- Service inputs
- Personnel-related expenses (travel, hotels…)
- Work-related employee expenditures (car,…)
- Delta-consumption due to employment demand
- (X) Total consumption of employees
- Profits (spending / re-investment)
- Taxes (spent by government)

Embodied energy burdens of inputs to computer manufacturing

	% to total upstream embodied energy	cumulative %
Air transportation	12%	12%
Electric services (utilities)	12%	24%
Computer peripheral equipment	10%	34%
Wholesale trade	10%	43%
Semiconductors and related devices	9%	53%
Petroleum refining	6%	59%
Other electronic components	5%	64%
Miscellaneous plastics products, n.e.c.	4%	68%
Relays and industrial controls	3%	71%
Gas production and distribution (utilities)	3%	74%
Automotive rental and leasing, without drivers	2%	76%
Hotels and lodging places	2%	78%
Telephone and telegraph apparatus	2%	80%
Aluminum rolling and drawing	2%	81%
Motors and generators	1%	83%
Blast furnaces and steel mills	1%	84%
Sheet metal work	1%	85%
Electron tubes	1%	85%
Nonferrous wiredrawing and insulating	1%	86%
Fabricated metal products, n.e.c.	1%	87%
Legal services	1%	87%
Paperboard containers and boxes	1%	88%
Motor freight transportation and warehousing	1%	89%
Power, distribution, and specialty transformers	1%	89%
Gaskets, packing, and sealing devices	1%	90%
Metal stampings, n.e.c.	1%	91%
Real estate agents, managers, operators, and lessors	1%	91%
Banking	1%	92%
Eating and drinking places	1%	92%
Management and consulting services, testing and research labs	1%	**93%**

Another eye-opener: *post-manufacturing*

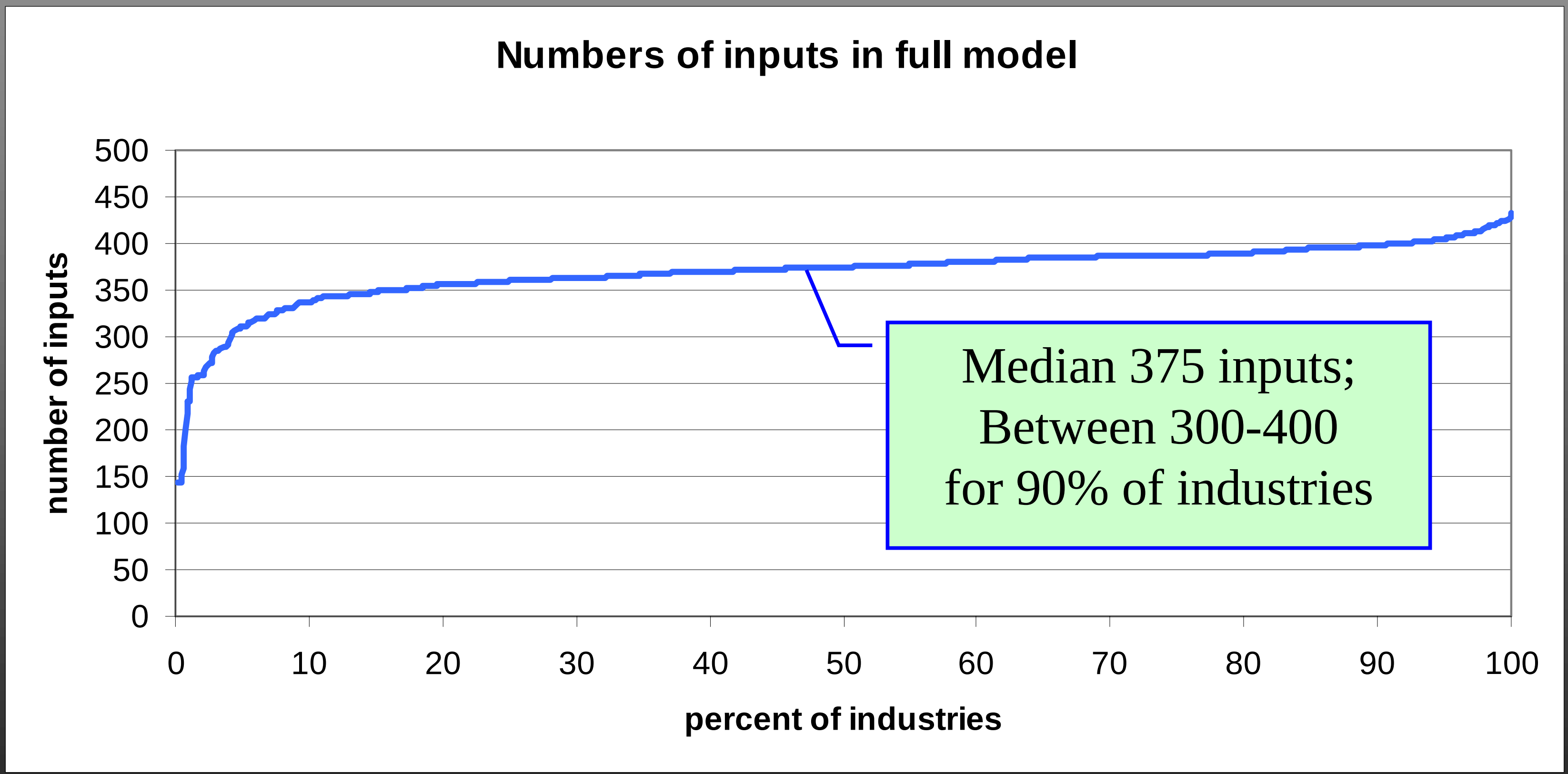


Embodied energy of different
pre-consumer life cycle stages for computers.

Input Boundary Issues

- *Which classes* of inputs?
- How many of the little inputs?

How many (little) inputs are there?



….Gimmie a break!

Are you saying that inputs of
pencils and lawyers’ fees and
air travel by the managers, etc.
make any real difference
in the LCI of a product?

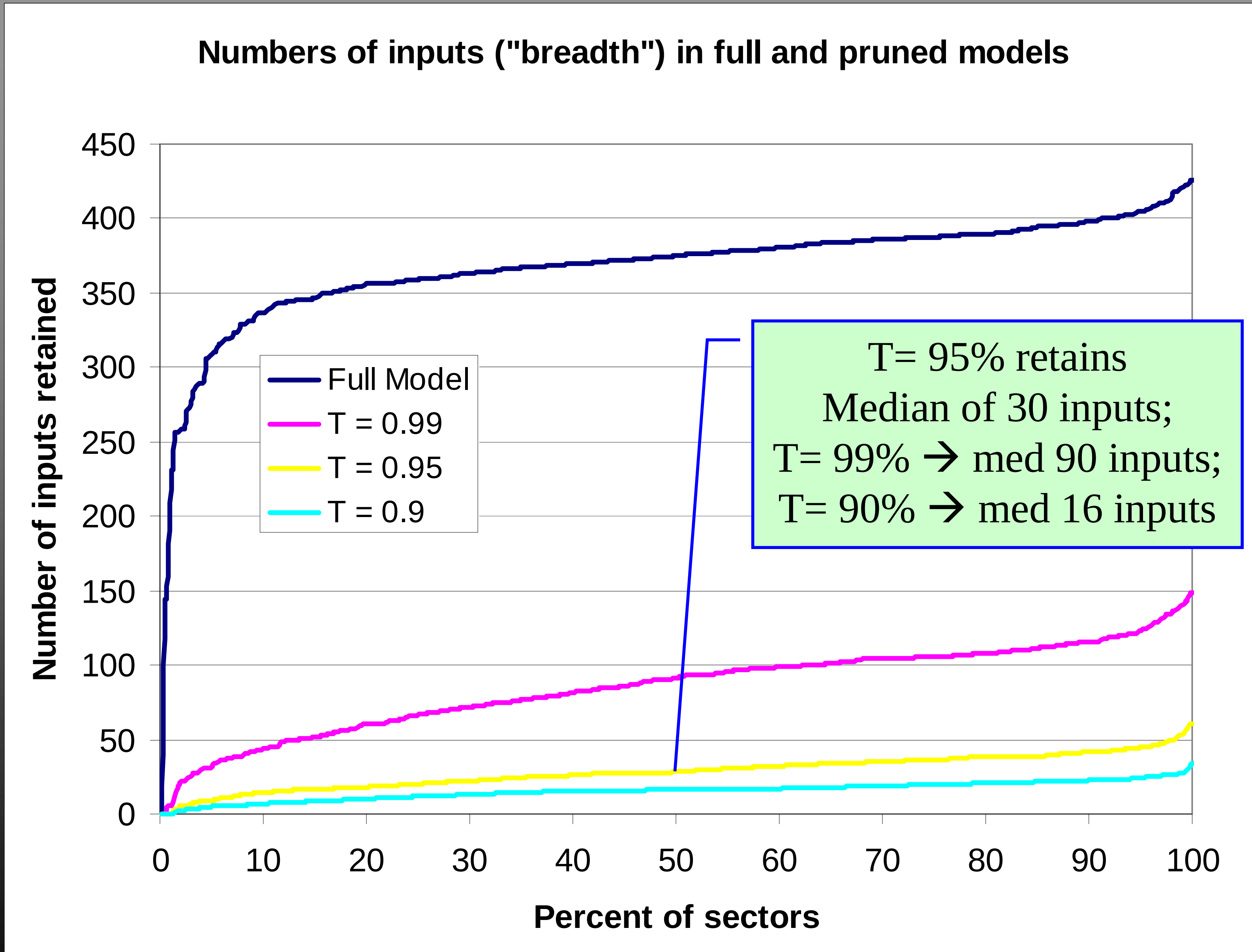
Let’s trim out the “little stuff” and see if anything changes in the LCI result.

"Tree pruning" algorithm

- For each industry, rank inputs in terms of their total (full-breadth model) upstream burdens (example uses fossil CO_2)
- Retain as many inputs as required so that

  Direct emissions + Σ retained = *T* (D + U)
- Create trimmed models for values of

  T = 99%, 95%, and 90%

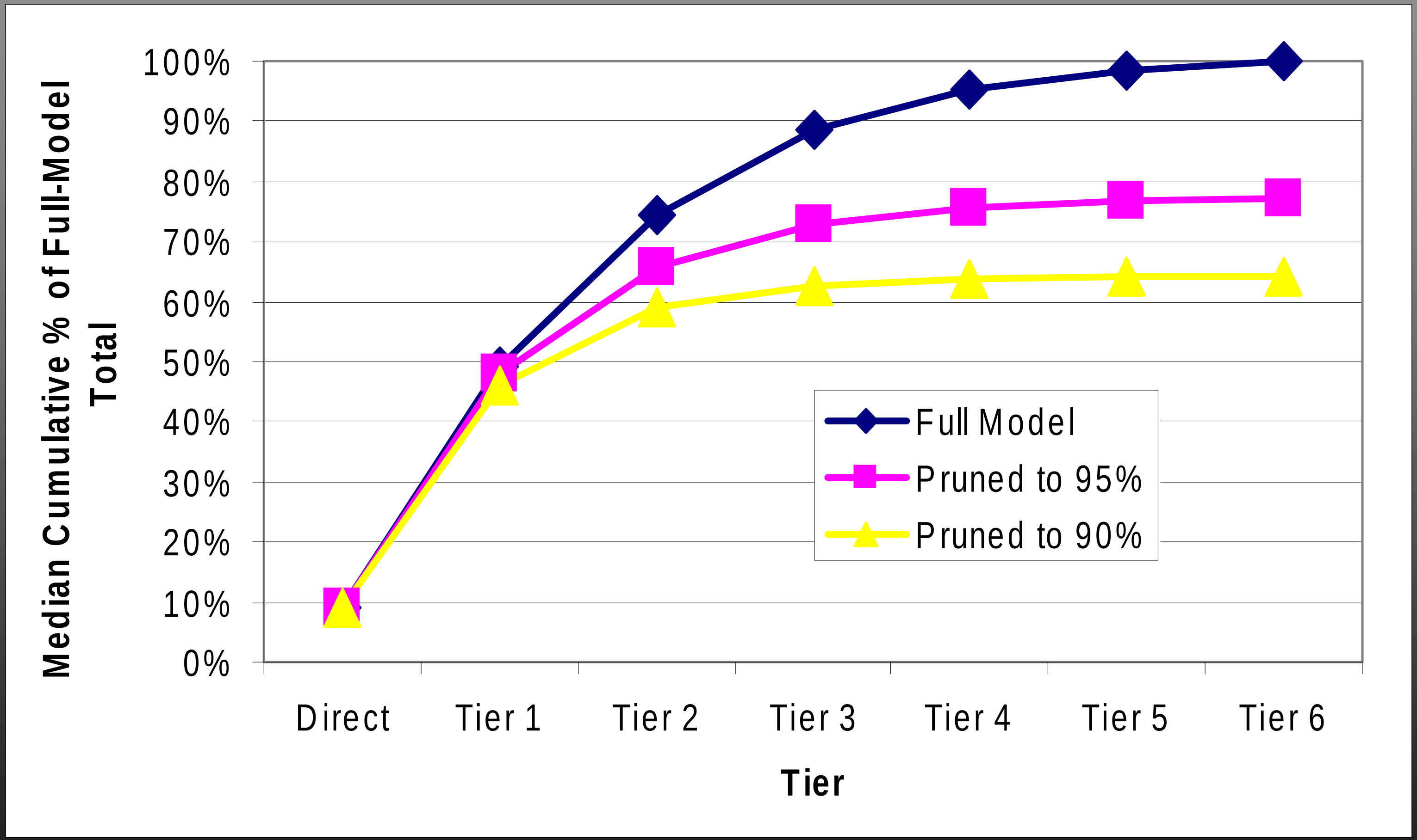


Numbers of inputs ("breadth") in full and pruned models
Number of inputs retained
Percent of sectors
0
50
100
150
200
250
300
350
400
450
0
10
20
30
40
50
60
70
80
90
100
Full Model
T = 0.99
T = 0.95
T = 0.9
T= 95% retains
Median of 30 inputs;
T= 99% → med 90 inputs;
T= 90% → med 16 inputs

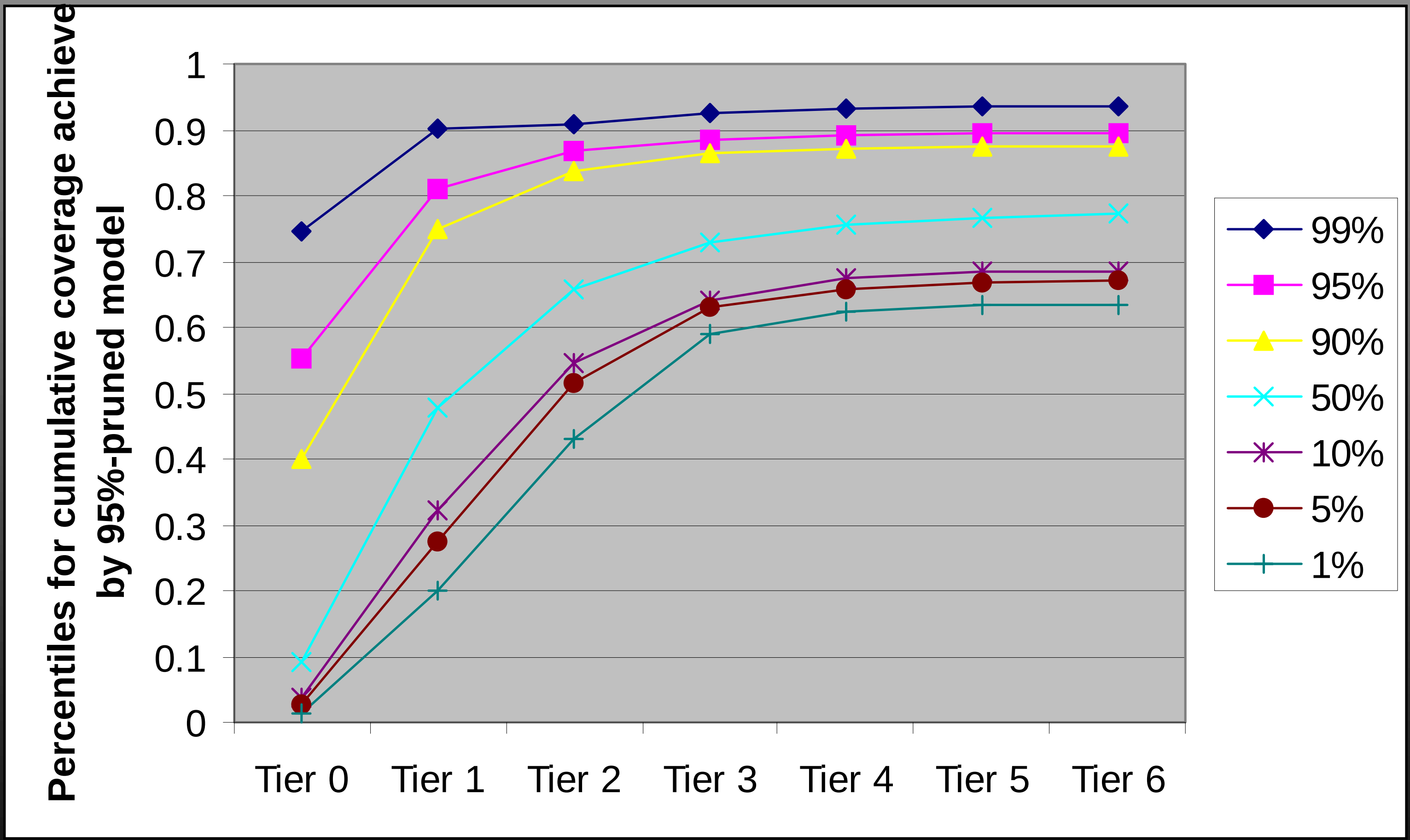
How well do the pruned models perform relative to full?

- Recall that threshold assumed *full* upstream modeling for all inputs
- Now, each sector is pruned, and so are all the sectors in its supply chain
- → consequences of system-wide use of cut-off rules

Performance of pruned models:
median cumulative % of 6-tier full-model total



Pruned model performance varies across products, even with consistent cutoff rule (Here T = 95%)



Input Boundary Issues

- *Which classes* of inputs?
- How many of the little inputs?
  - For fossil fuel plants, capital goods found to account for ~ 5% of criteria air emissions
  - Other input classes not yet studied
  - For renewable power, non-conventional input modeling could *double* LCI results

Other Boundary Issues

- Geographic scope
  - Proper region for electricity supply
  - Foreground / Background
- Temporal scope
  - Long-term impacts (nuclear waste)
  - Discounting of impacts? (LCIA)

Marginal vs. average data
(system expansion vs. allocation)

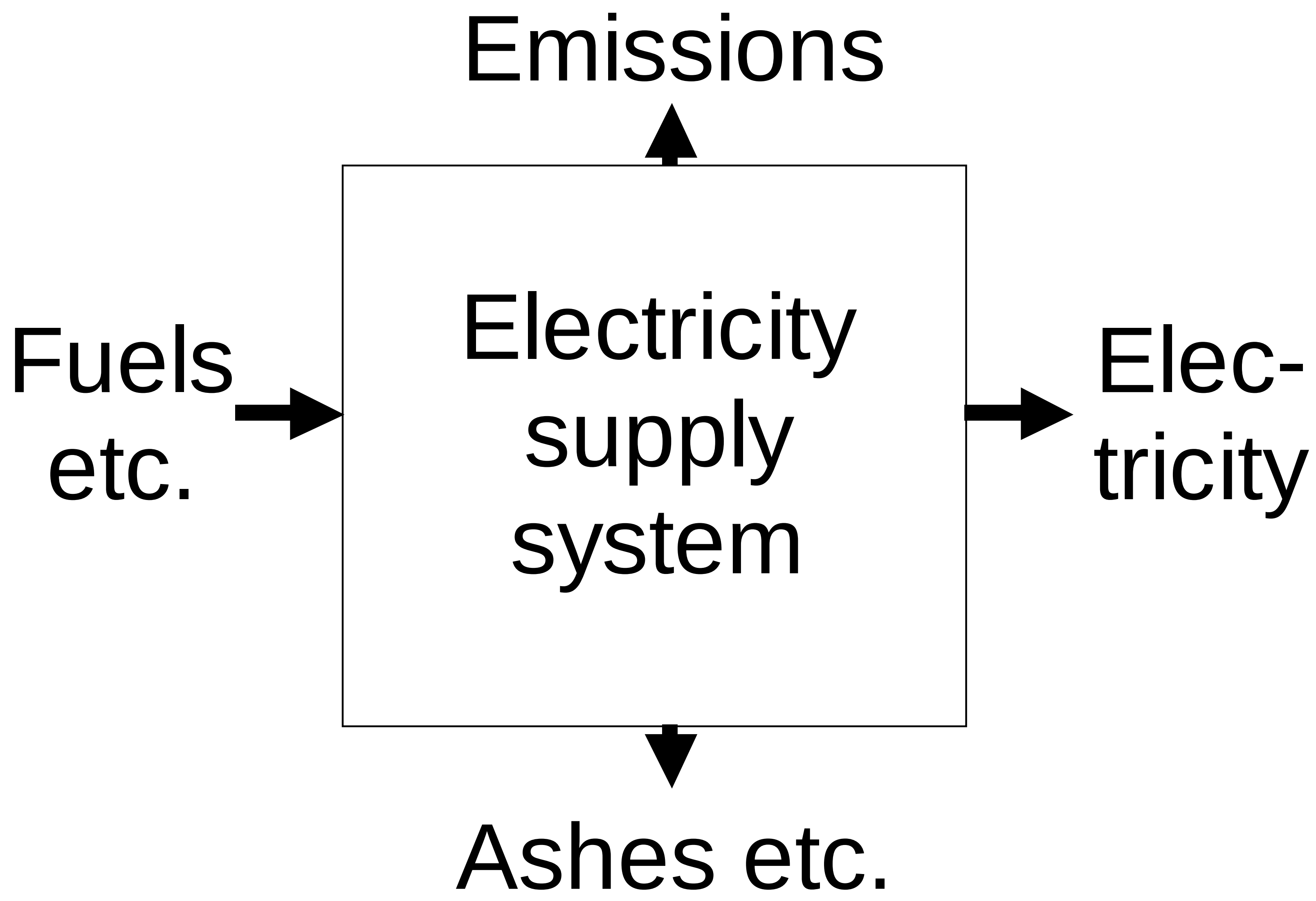
Tomas Ekvall
Chalmers University of Technology
Gothenburg, Sweden

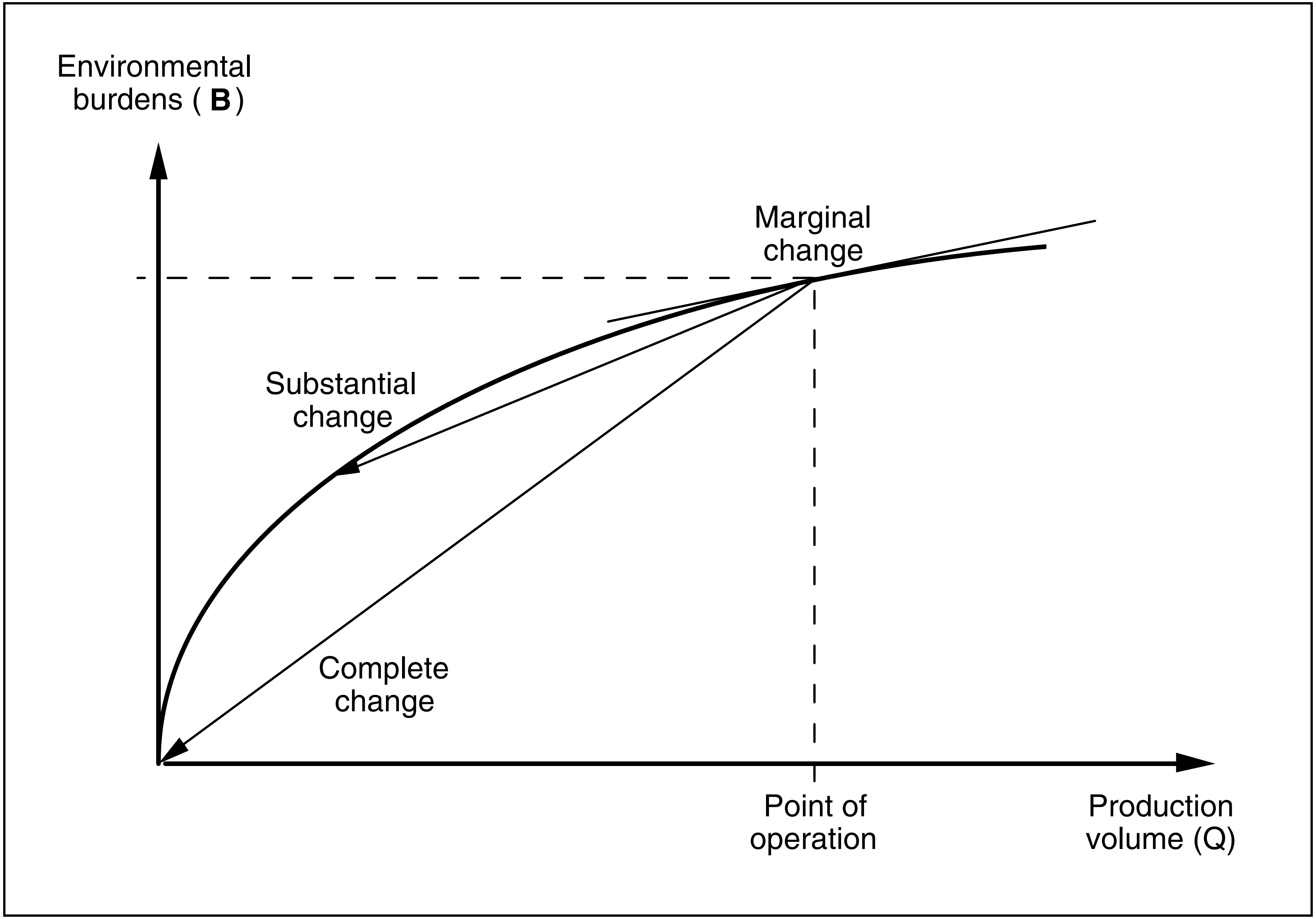
Int. Workshop on Electricity Data for Life Cycle Inventories
Cincinnati, October 23-25, 2001

Statement 1

- Average data describe systems

- Marginal data (attempt to) describe consequences

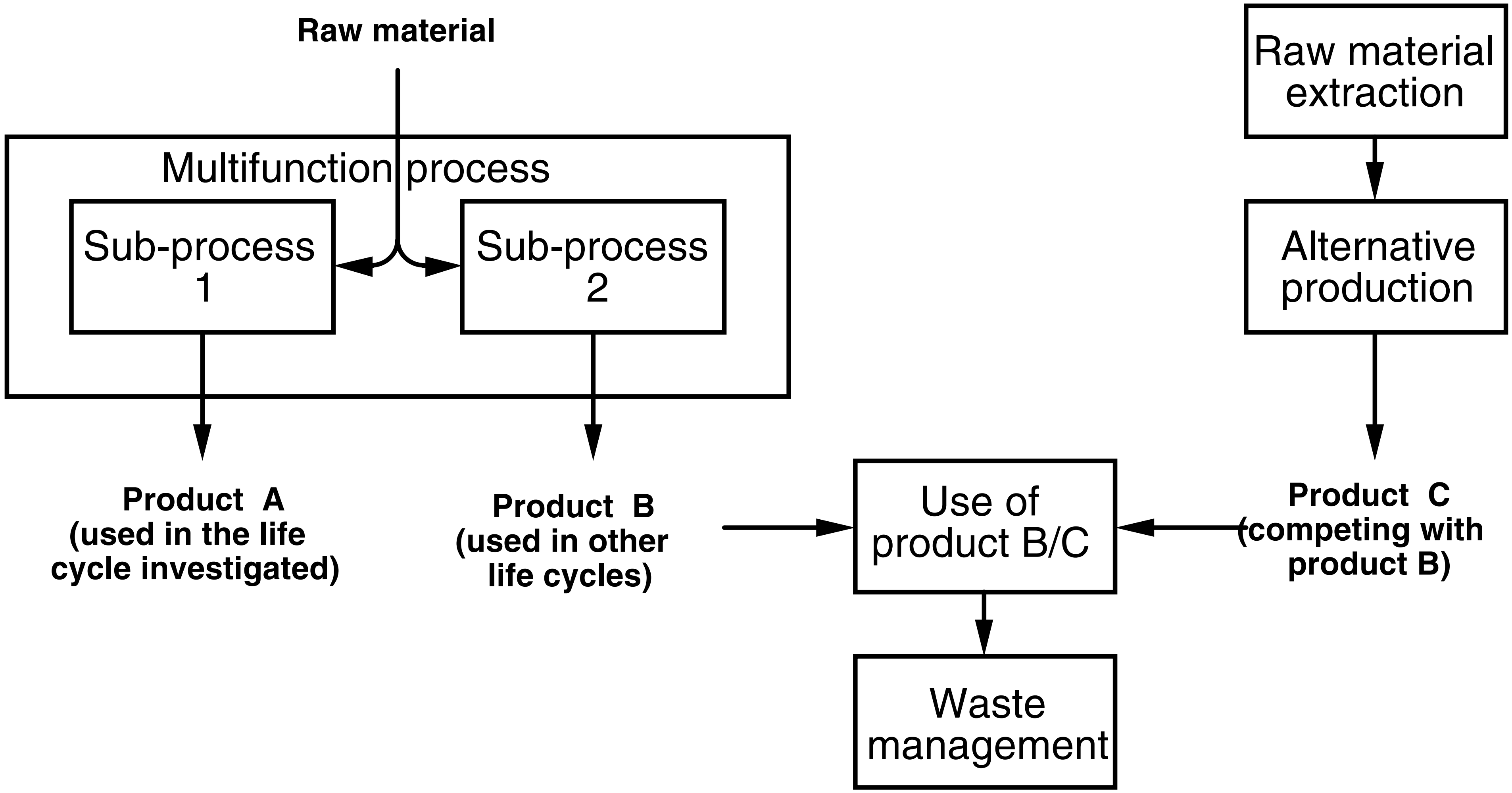

Emissions
Fuels etc.
Electricity supply system
Elec-tricity
Ashes etc.


Environmental burdens (B)
Marginal change
Substantial change
Complete change
Point of operation
Production volume (Q)

Statement 1'

- Allocation (attempts to) describe systems

- System expansion is often required to describe consequences


Raw material
Multifunction process
Sub-process 1
Sub-process 2
Product A (used in the life cycle investigated)
Product B (used in other life cycles)
Use of product B/C
Waste management
Raw material extraction
Alternative production
Product C (competing with product B)

Statement 2

Both can be relevant for…

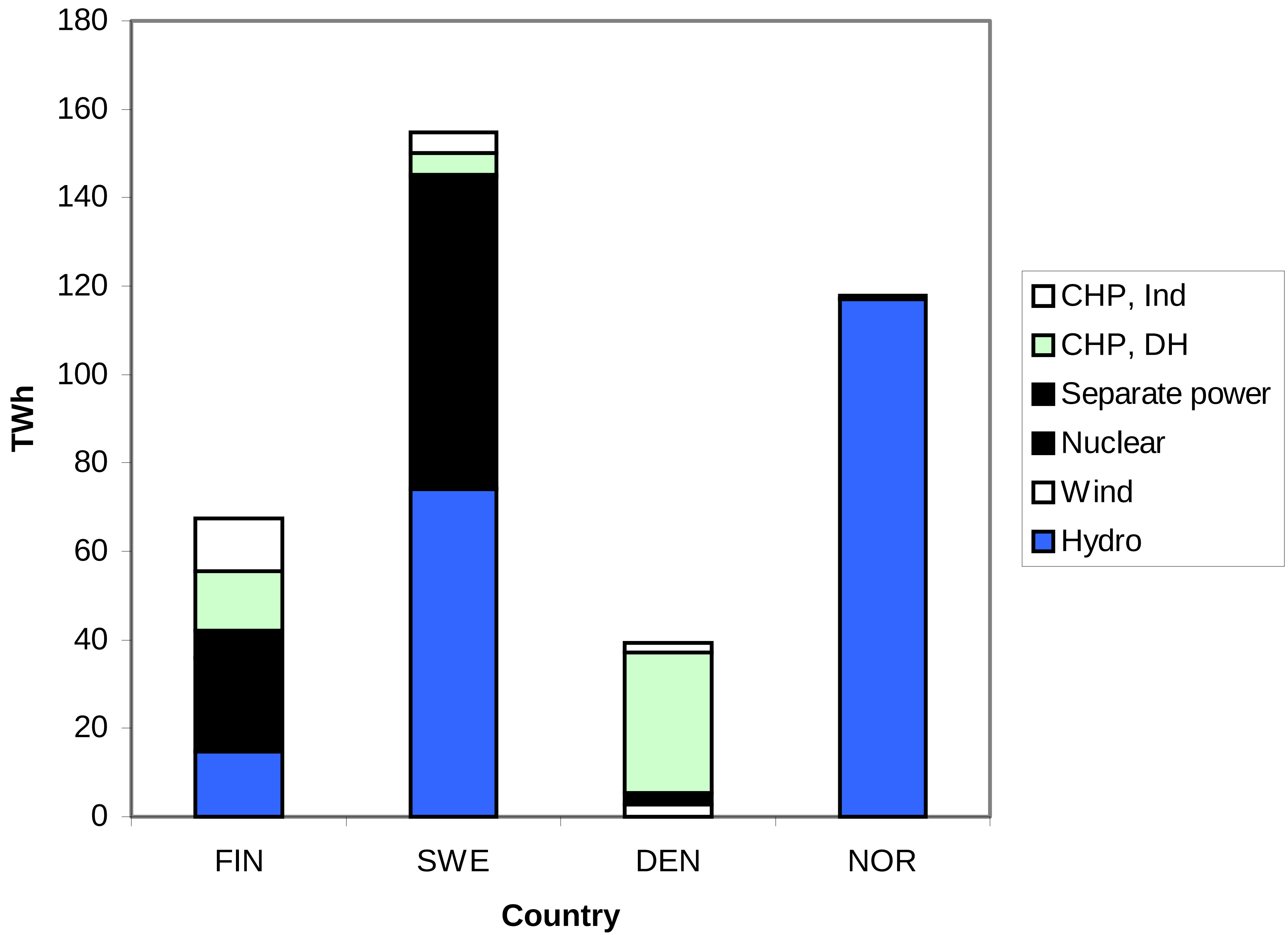
- …historic & future oriented LCA
- …foreground & background system
- …learning & decision-making context

	Foreground	**Background**
Learning	Average	Average / marginal
Decision making	Average / marginal	Average / marginal

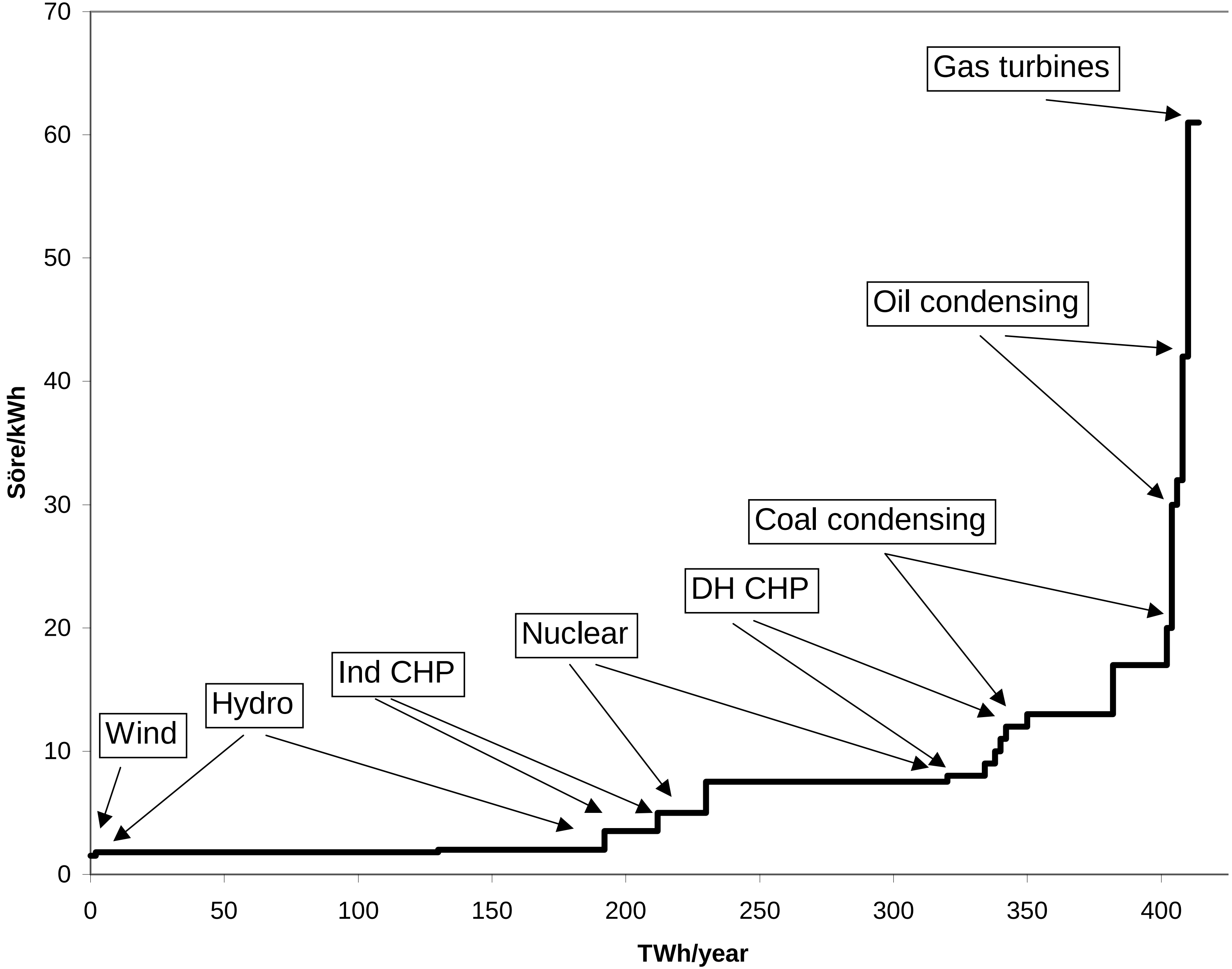
Statement 3

Both have limitations

- Relevance: system vs. consequences
- Accuracy: subjectivity vs. uncertainty



180
160
140
120
100
80
60
40
20
0
TWh
FIN
SWE
DEN
NOR
Country
CHP, Ind
CHP, DH
Separate power
Nuclear
Wind
Hydro



Gas turbines
Oil condensing
Coal condensing
DH CHP
Nuclear
Ind CHP
Hydro
Wind
Söre/kWh
TWh/year
0
10
20
30
40
50
60
70
0
50
100
150
200
250
300
350
400

Suboptimal action

Support good systems

=>

Primary aluminium investment in Norway

=>

Increased electricity production in Denmark

=>

Poor consequences

Suboptimal rule

Aim at good consequences

=>

No comparative advantage for Norway

=>

Isolated Norwegian electricity system

=>

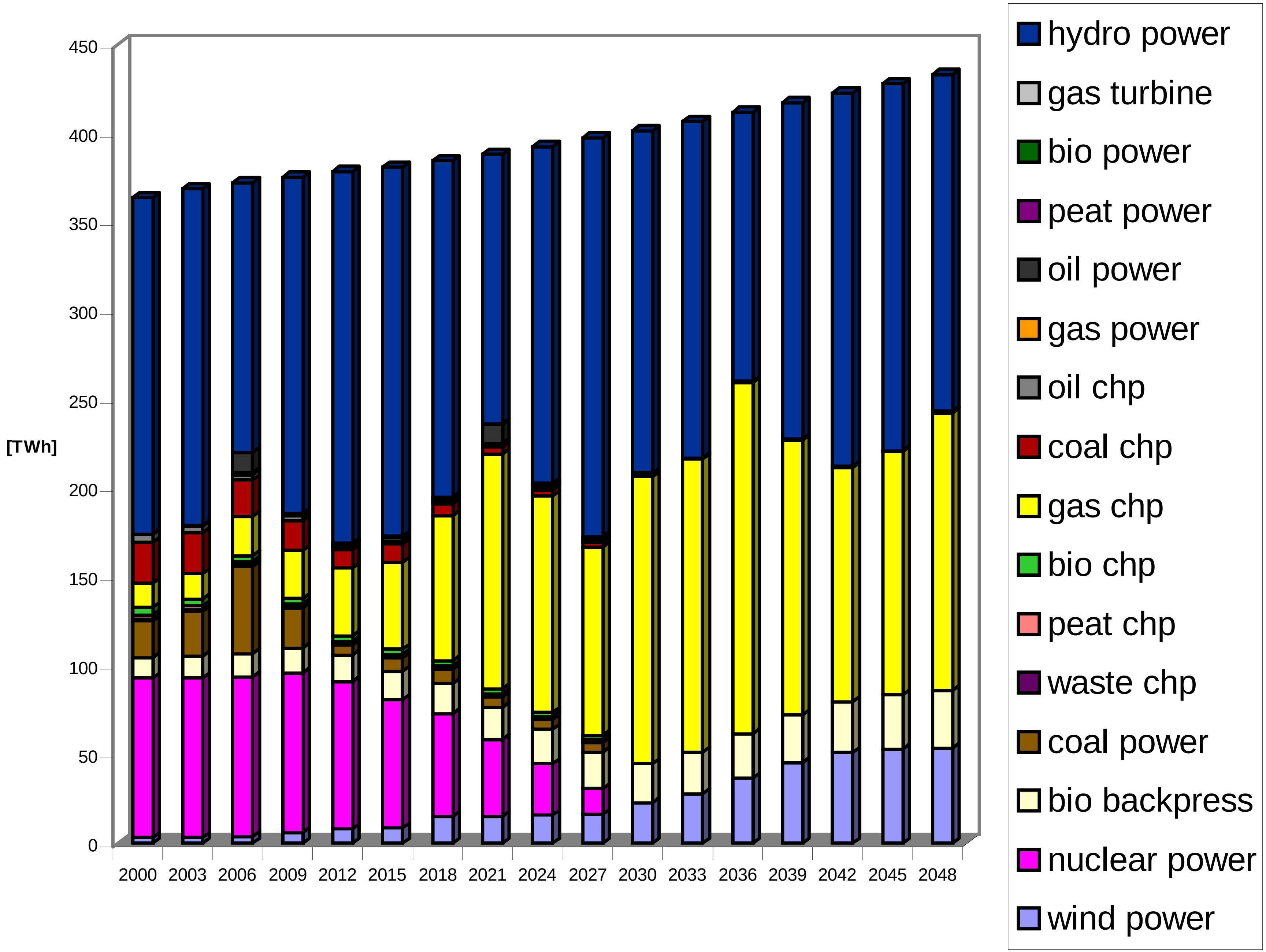
Poor electricity system

Subjective choice of system

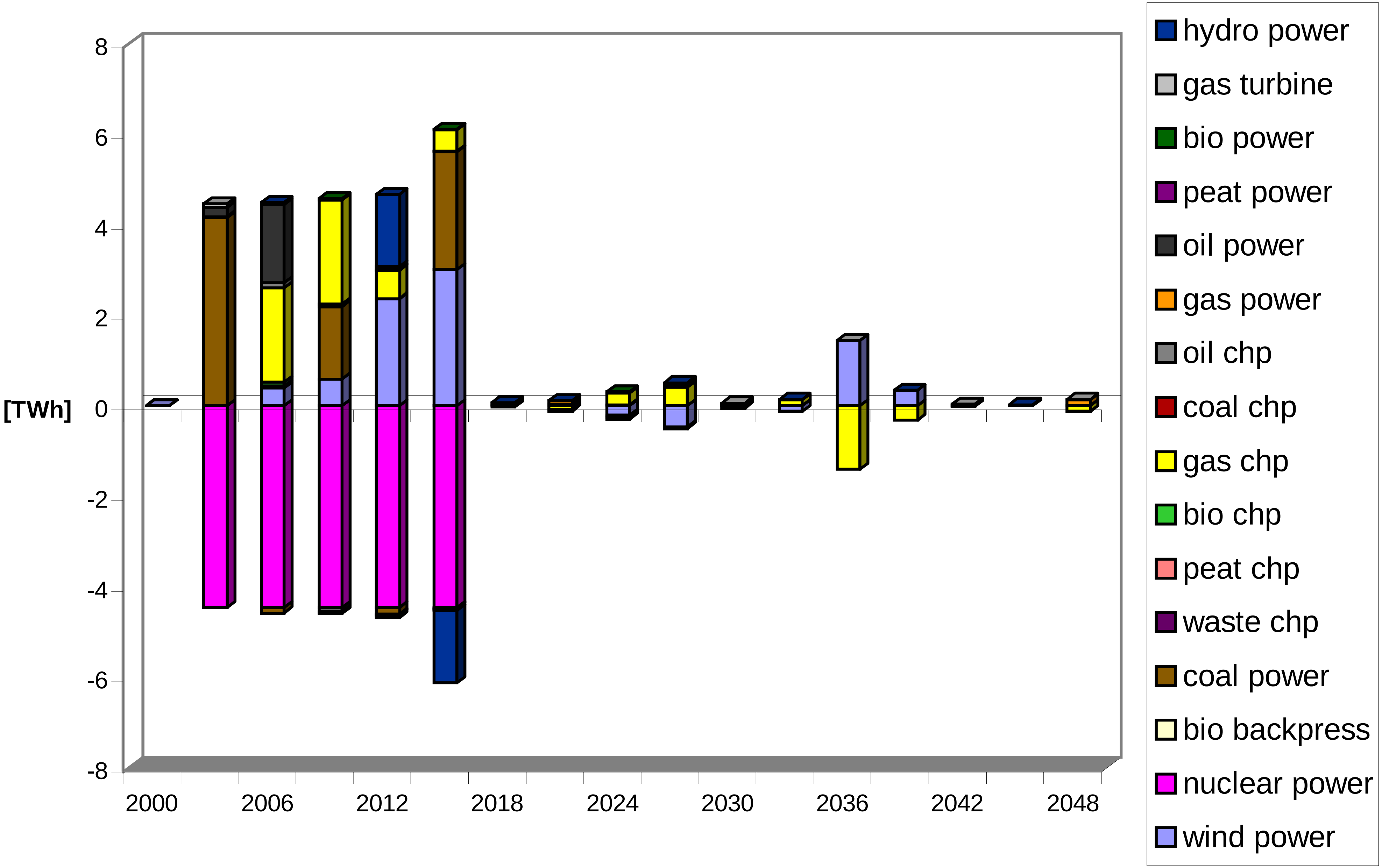
- Specified technology or plant
- Electricity utility
- Regional grid
- National grid
- International grid

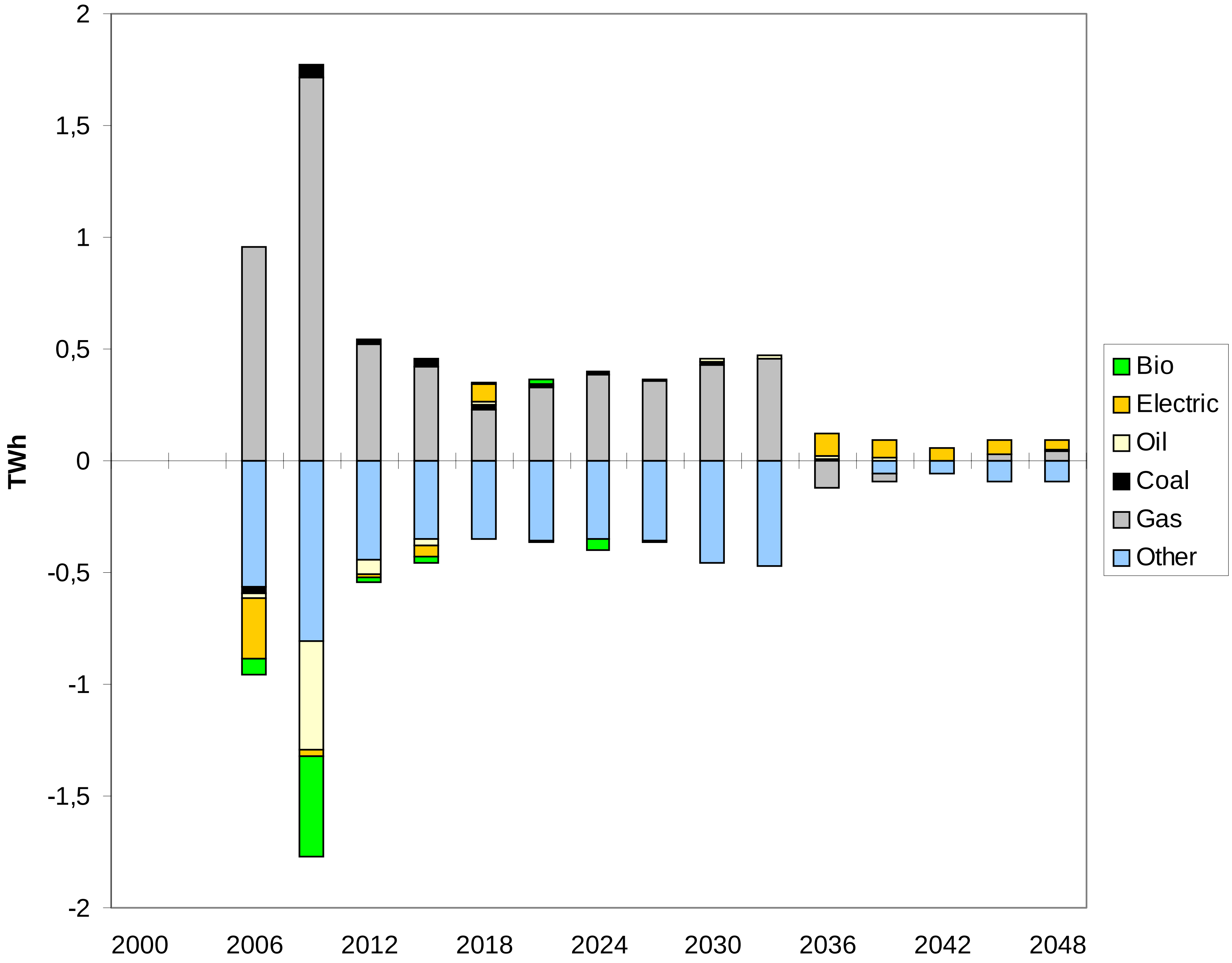
Uncertain modelling of consequences

- Complex and uncertain margins
- Consequences beyond the models



[TWh]
450
400
350
300
250
200
150
100
50
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
hydro power
gas turbine
bio power
peat power
oil power
gas power
oil chp
coal chp
gas chp
bio chp
peat chp
waste chp
coal power
bio backpress
nuclear power
wind power


8
6
4
2
[TWh] 0
-2
-4
-6
-8
2000
2006
2012
2018
2024
2030
2036
2042
2048
hydro power
gas turbine
bio power
peat power
oil power
gas power
oil chp
coal chp
gas chp
bio chp
peat chp
waste chp
coal power
bio backpress
nuclear power
wind power


2
1,5
1
0,5
0
-0,5
-1
-1,5
-2
TWh
2000
2006
2012
2018
2024
2030
2036
2042
2048
Bio
Electric
Oil
Coal
Gas
Other

What consequences are in the model?

- Physical cause-effect relations
- (Economic relations)
- ~~Psychological relations~~

Statement 4

- Full consequences are utterly uncertain

- This should be no barrier

Conclusions

- Marginal and average data give different information
- Allocation and system expansion give different information
- No clear-cut ranking
- Consider the audience
- Communicate clearly

New and Non-traditional Generators

International Workshop on Electricity Data for Life Cycle Inventories

Margaret Mann
National Renewable Energy Laboratory
Golden, CO USA

Areas of Interest

- Conceptual technologies
- Renewables
- Non-baseload
- Distributed generation

- Key issues – why should we care?

Conceptual Technologies

- Perhaps still in R&D stage
- Little operating data
- Site not yet defined
- Operating conditions difficult to predict
- Often viewed as more environmentally benign
- Power examples: fuel cells, microturbines, advanced biomass, new PV, new nuclear, advanced coal

Key Questions for LCAs on Conceptual Technologies

- How do you compare a new technology to one that is well defined?
- How do you take into account higher level of uncertainty?
- How do you define a reliable set of data for an R&D project?
- How do you take into account lack of site-specific information?
- To what extent should assessment be qualitative rather than quantitative?

Renewables: a special case

- Many have low, or essentially no, operating emissions
- How should construction emissions be allocated to kWhs generated over lifetime?
- Impacts may be different (e.g., land-use and bird kills vs natural resource consumption and greenhouse gases)
- What is the appropriate use of LCA in green power certification? In regulation?
- Key driving factor: avoidance of conventional environmental impacts - need to standardize treatment of this in LCA

Non-baseload Generators

- Many new systems do not produce power on a continuous or controllable basis
- What is functional unit?
  - Supply based: kWh from intermittent source
  - Demand based: kWh needed to meet load
- How are emissions of supplemental system allocated?
- How do we compare the emissions/kWh from intermittent sources to those from baseload generators?

Distributed Generation

- Drivers:
  - Demand for reliable power
  - Avoidance of down-time costs
  - Avoidance of T&D infrastructure
  - Mitigates large up-front capital expenditures
- Potential is significant
- Not point-source emitters
- Credit for T&D losses; not traditionally assessed to large-scale generators
- May be operated intermittently
- What about hybrid systems?
- Key: functional unit may not be kWh

Key Issues for LCI

- Mix of technologies is not static
- In LCI, how do we take into account dynamics of technologies and grid?
- What about the potential for very different grid mixes in the future?
- Different locations will see varying rates of change – how will this affect relative impacts of products?
- What would be the value of a stochastic model that gives probabilistic ranges of stressors?

Generalized Questions

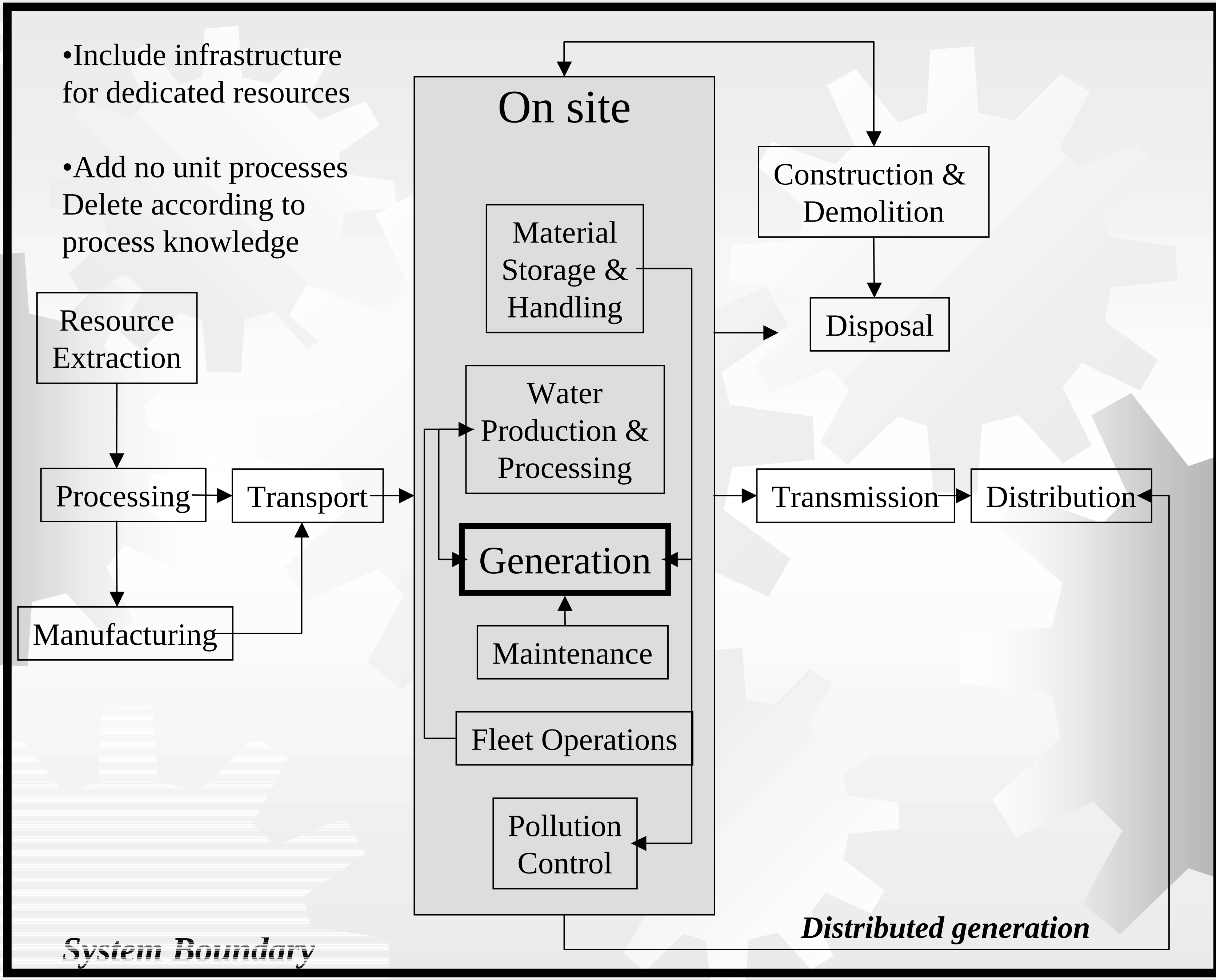
- Can LCAs be conducted on new technologies for which production data are not available?
- Is there a need to develop a common future energy scenario that considers renewable and distributed energy sources for use in prospective LCAs?
- How should distributed generation be accounted for in national or regional energy grid data?
- What percent of the grid mix does a technology have to supply before we care about it in our product LCAs?

Boundaries and Flows

24 October 2001

Cincinnati

Electricity LCI Workshop


•Include infrastructure for dedicated resources
•Add no unit processes Delete according to process knowledge
Resource Extraction
Processing
Transport
Manufacturing
On site
Material Storage & Handling
Water Production & Processing
Generation
Maintenance
Fleet Operations
Pollution Control
Construction & Demolition
Disposal
Transmission
Distribution
Distributed generation
System Boundary

FLOWS

Not a comprehensive list, but a minimum list

Resources

- Electricity (location)
- Water (location & type)
- Fuel (in ground)
- Minerals (in ground)
- Biomass (harvested)
- Land use (area & location)

Wastes

- Solid waste
- Radioactive Waste (high, low, medium)
- Hazardous Waste

Air

- CO_2
- CO
- PM (10, 2.5)
- CH_4
- SO_X
- NO_X
- NH_3
- Hg
- Pb
- VOC (NM)
- Dioxin
- PAH's

Water

- COD
- TDS
- TSS
- BOD (5,7,10)
- Flow

ΔTemperature
- NH3 (as N)
- TKN (as N)
- NO3, NO2 (as N)
- PAH's
- Phosphates (as P)
- Cu
- Ni
- As
- Cd
- Cr
- Pb
- Hg

Rules & Advice

- Follow the ISO 14040 standards
- Don't add unit processes to system
- Delete unit processes only based on process knowledge
- Get inventory for all suggested flows, filling in gaps as needed
- Don't throw away data (it may someday be important) but
- Remove from consideration those data which are not in your impact assessment model

Next Step: Model Examples

- Coal w/ anthracite
- Coal w/lignite
- Natural Gas
- Oil
- Nuclear
- Hydro
- Wind
- Biomass
- Geothermal
- Other

Research Opportunities

- Biological Resources
- Radiation
- Noise

New and Non-traditional Generators

Merwin Brown
Joyce Cooper
Rolf Frischknecht
Douglas Gyorke
Marty Heller
Wolfram Krewitt
Ivars Licis
Lynn Manfredo
Maggie Mann
Jonathan Overly

Group Kept Asking....

- Who are we?
  - Database developers
  - LCA practitioners
- What is the purpose of the LCA?
  - Came up with 17 different uses
  - Doesn’t matter for our purpose today

Questions

- Can LCAs be conducted on new technologies for which production data are not available?
  - How are data sets constructed for new technologies, for which there are higher degrees of uncertainty in environmental stressors?
- Is there a need to develop a common future energy scenario that considers renewable and distributed energy sources for use in prospective LCAs?
- How should distributed generation be accounted for in national or regional energy grid data?
  - How should distributed generation be accounted for in national or regional energy grid data?
- What percent of the grid mix does a technology have to supply before we care about it in our product LCAs?

Answers to Q1

How are data sets constructed for new technologies, for which there are higher degrees of uncertainty in environmental stressors?

a. Use best available mass & energy & production data.
b. Where there are data gaps, make a conservative expert judgment for missing data points and document assumptions (SETAC working group)
c. Include a calculation routine that allows the users to vary performance/emissions parameters.
d. Document assumptions, sources of data, and year in which data were obtained.
e. Be alert to the situation where you need to input stressors that are not common to current generation technologies (e.g., bird kill, land use).

Answers to Q2

Is there a need to develop a common future energy scenario that considers the use of renewable and distributed energy sources in grids.

a. No.
b. However, there is a need to provide for the application of various future energy scenarios.
c. Provide a tool or modules that describe different energy mixes/scenarios.

Answers to Q3

How should distributed generation be accounted for in national or regional energy grid data?

a. The same way that traditional generators are accounted for.
b. Different transmission and distribution losses are important.

Answers to Q4

What percent of the grid mix does a technology have to supply before we care about it in our product LCAs?

a. If you can do an LCA on a technology, provide it in the database.

b. Use the module/tool described in 2) to give the user an opportunity to incorporate them into their grid mix, or they can do it manually.

Other key points

- Database data should be as un-aggregated as possible.
- Functional unit should always be kWh, but…
  - Database: kWhs from generation technology
  - User: kWhs from all sources that generate electricity being used
- Assessments (and underlying database) should be done in three separate steps: construction, operation, decommissioning. Start-up should also be considered separately.

Attributional & Consequential

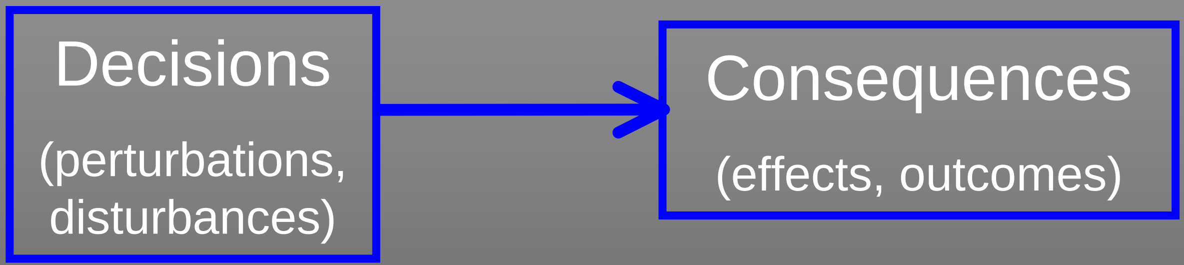
EPA Workshop on

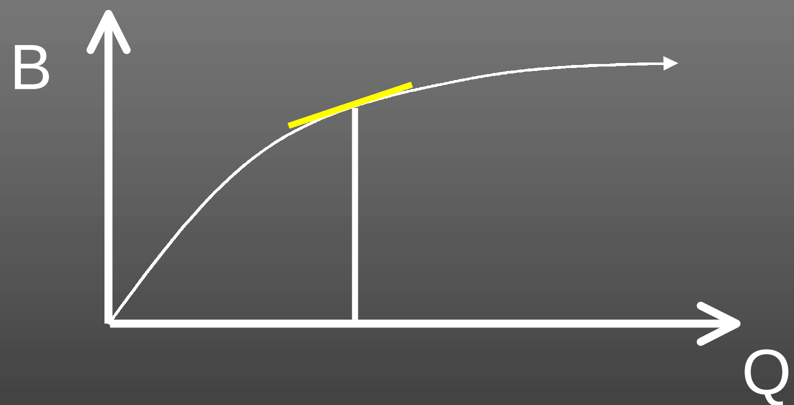
LCA of Electricity Supply

Our mission

- Clarify terminology, meanings
- Different or similar:
  - Electricity LCI for use in other LCIs
  - LCI compare electricity generation options
- When are attributional and consequential each appropriate
- Feasibility of each, applied to electricity
  - Cost and time
  - Data availability, quality, uncertainty
- How-to, implementation, models

Terminology

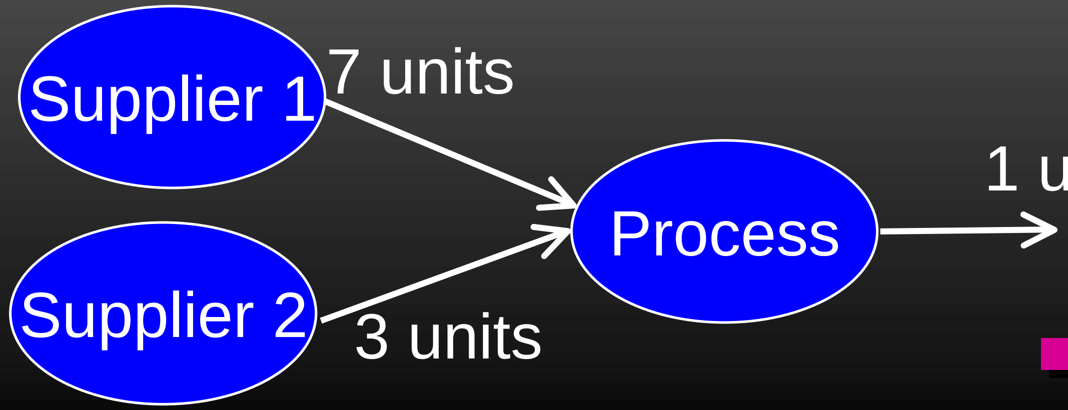




- Each can have
  - Timing and duration
  - Magnitude
    - Marginal perturbation = infinitesimal disturbance
    - Marginal consequences = consequence per unit of perturbation (limit as Δdisturbance $\rightarrow$ 0)

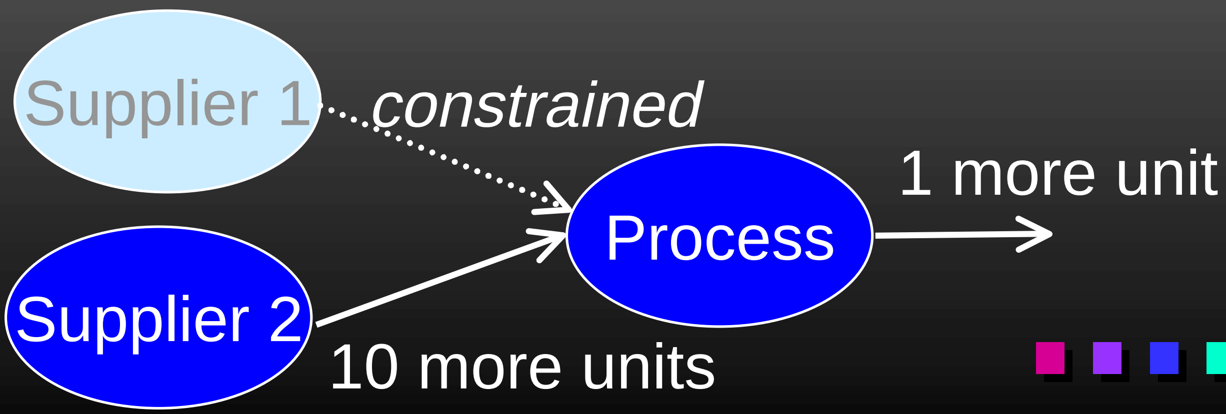
Attributional Approach

- Traditional approach
- Allocates, attributes blame, credit, burdens to products, given system as it is.
- Rules to define system: sources of inflows
- "How do things flow, in the system, during the specified time window?" (past, present, future)



Consequential Approach

- Attempts to assess decision consequences
- "How will flows change as a result of decisions?"
  - Short-term (Δ output from existing capacity)
  - Long-term (Δ capacity investments)
- Could be past, present, or future



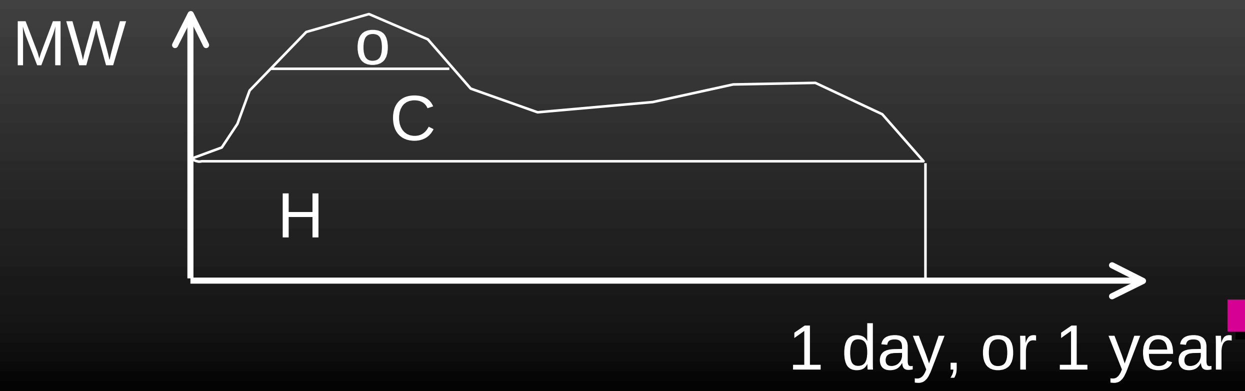
Example LCA Decisions involving electricity

- Where to build a new aluminum plant?
- Government: new appliance standard
- Chemical process modification
  - More electricity use, less chemical use
- Market penetration of high efficiency motors.

- → Agreement: "Ideally", LCA tells decision maker about consequences of each decision

Reality

- How *DOES* the electricity system respond to changes in demand?
  - Short term: demand changes occur at operating plants with highest variable cost
  - Long term: new capacity is one most profitable, depends on load shape (hourly, seasonal)
  - Evolving, dynamic; future is uncertain



Energy system models

- Dynamic
- Causally descriptive
- Can be used to estimate how system in different regions responds to demand changes with different seasonal/hourly profiles, different magnitudes
  - → which plants affected how much, when?
- Chalmers example

Consequential LCI not familiar to practitioners → questions, apprehension

- Questions
  - Does C/A effect LCI results? How much? When? Which product types, regions?
  - Does it alter LCI-based decisions?
  - How easy to explain? (*)
  - How easy to perform?
- Apprehension
  - Today's databases are attributional
  - Today's *brains* are attributional

Recommendations

- Need LCI databases that are technology-based
  - Don't aggregate over different technologies
  - Don't aggregate over markets
  - → Solving confidential information issues
- Need ample meta-data
- Need feasibility studies of applying energy system models to generate LCIs for 1 kWh, e.g., different load shapes
  - → Address questions arising from "unknown"

Thanks

- To approximately 30 people, 20 at any one time, who
  - Traveled far
  - Worked and thought hard
  - Stayed friendly
  - Learned things
  - Produced understanding