Improving life cycle assessment methodology for the application of decision support - DTU Orbit (23/12/2018)

Improving life cycle assessment methodology for the application of decision support: Focusing on the statistical value chain

There have been two overall objectives for this PhD thesis:

a) To improve the life cycle assessment (LCA) methodology for the application of decision support and evaluation of uncertainty in LCA.

b) Improving the LCA methodology for the application of decision support and evaluation of uncertainty in LCA.

From a decision maker's (DM's) point of view there are at least three main "illness" factors influencing the quality of the information that the DM uses for making decisions. The factors are not independent of each other, but it seems helpful to use the following separations for clarification:

- Uncertainty
- Costs
- Time

Improvements in just one of these three factors can swiftly lead to an improvement of the others since they are highly dependent on each other. The focus of this PhD project has been on uncertainty.

Most application-oriented LCAs are used as an "overall linking" decision support tool, meaning that they summarize relatively large amounts of data mainly collected in the literature (e.g. articles, various databases and reports), which rarely gives anything other than point estimates (such as an average value). Previous methods for evaluation of uncertainties in LCA have mainly been based on estimates from experts and variation expansion, for example by using Monte Carlo simulation.

The methods and theories upon which this PhD thesis is based are mainly from the management literature (especially the rational school of management) and the statistical literature.

My suggestion for improved LCA methodology is based on what I regard as the "statistical value chain", which is summarized below. Understanding the statistical value chain will increase the possibility for DMs, LCA experts, analysts (ANs), etc., to pinpoint where uncertainties may arise in LCA.

The statistical value chain

The world is as it is at any given time (Pt). How the world was at Pt-1 ... t-m is undeniable. Prospectively we presume to influence how the world will be for Pt+1...t+n.

Step 1: Defining the population that will be investigated: For information about the world, we need to collect empirical data. We cannot collect data on the entire world, but we need to collect data on the population(s) that we are making enquiries into. The starting point of a data collecting process is to outline (or define) the population that will be investigated, both with regard to space and time.

Step 2: Full investigation/Theory of Sampling (TOS): When a population has been defined, we then have two options for seeking information: A) seek full information (i.e., examine each population as a whole) or B) use representative sampling and then generalize to the full population that the LCA used for decision support aims to describe. Only well-used sampling procedures described by TOS can lead to representative sampling of population(s). TOS is often used to as a method to save resources compared to investigating the complete population.

Step 3: Descriptive statistics: Descriptive statistics is about computing averages, variation analysis, minimums and maximums, distributions, etc. of the different populations investigated in step 2.

Step 4: The retrospective LCA: As long as a given LCA can be categorized as a retrospective assessment it is, in this PhD thesis, assumed that LCA is a matter of accounting and based on the previous steps this accounting is, more or less, straight forward and the accounting should cover the total LCA system, i.e. all populations. This step is analogous to a company's financial statement.

Step 5: Developing the baseline for prospective LCA: The first step in prospective assessment is to construct a baseline, which can be characterized by: "exactly what (you think) will happen if the change under consideration was not introduced" (business-as-usual). The following step (step 6) outlines methods for the prospective LCA.

Step 6: Inferential statistics: By the use of inferential statistics we can construct models, i.e. establish relationships and correlations between the different populations investigated in the previous steps. Based on the model developed we can produce forecasts/predictive analysis for Pt+1...t+n.

Step 7: Alternatives: All relevant alternatives to the baseline study in step 5. The difference between the baseline study and alternatives provide the potentials for improvements/changes (both positive and negative).

Step 8: Valuation: Here, valuation is meant as a sum of all humans' utility of the conditions given/estimated in steps 1-7. The statistical value chain should not be interpreted as a rigid procedure where the AN starts at "step 1" and ends at "step 8". The process of developing an LCA used for decision support is an iterative process with an ex-ante (priori) to the LCA project start unknown number of N-steps, going back and forth between the different steps. A deterioration of the quality in each step is likely to accumulate through the statistical value chain in terms of increased uncertainty and bias. Ultimately this can make final decision support problematic.

The "Law of large numbers" (LLN) is the methodological tool/probability theory that has been used consistently throughout this PhD thesis and forms the basis for evaluating the inherent uncertainty in different types of LCAs. The LLN is here interpreted as: "the larger a sample (n) from a given population is, the more accurate the estimate of the true average of the population (N) will be". Furthermore, I have assumed that N can be interpreted as the LCA space that we are making LCA statements about. An LCA statement is the answer to an LCA question (or inquiry). Based on the LLN it can be seen that reducing uncertainties in LCA is probably not possible to do in ways other than to A) use more resources on a given analysis, or B) reduce the size of the LCA space into which inquiries are made.

The above statistical value chain together with LLN is explored in the article "Confronting uncertainty in LCA used for
decision support*, which is submitted to the Journal of Industrial Ecology. This article presents a simple but powerful, methodical tool (a pedigree matrix) to assess and potentially confront uncertainties in LCA based on a developed taxonomy used for classification of different types of LCAs. Use of this tool may lead to an increased transparency (or reduced obscurity) for the DM through a potentially quick identification of “what is included in the LCA and what is not”. It is also discussed in this article that the accepted uncertainty level is decision support context depending and also personal. This may then cause the situation where some DMs completely (or partially) refrain from making a decision based on an LCA and thus support a decision on other parameters than the LCA environmental parameters. Conversely, it may in some decision support contexts be acceptable to base a decision on highly uncertain information. This all depends on the specific decision support context and it is not possible to derive objective rules about what one ought to do. This is the “is-ought” problem as formulated by the Scottish philosopher David Hume in 1739. For example, it is an “is-issue” what the uncertainty in a given information is (from a statistically point-of-view), but it is an “ought-issue” whether the DM ought to base a decision on information with a high/low degree of inherent uncertainty. In the article "Does it matter which LCA tool you choose? - comparative assessment of SimaPro and GaBi on a biodiesel case study", which has been submitted to the International Journal of Life Cycle Assessment, it is shown that already by step 4 in the statistical value chain there can be considerable uncertainties in an applied LCA used for decision support.

LCA of biodiesel from a WTW perspective
This PhD project has two main stakeholders: Emmelev A/S (biodiesel producer) and Novozymes A/S (enzyme producer), both with the goal of developing an enzymatic transesterification process that would be environmentally preferable compared to the current conventional alkaline transesterification process. Based on the data available during the project period, it has not been possible to demonstrate that an enzymatic transesterification process (evaluated on a CO2–eq. emission scale) is preferable compared to the conventional process. However, given that the enzymatic process enables the use of bioethanol (instead of petrochemical methanol), then the enzymatic process improves biodiesel from a WTW perspective, i.e. the change from petrochemical methanol to bioethanol is a benefit that exceeds the negative effect of transitioning from a conventional to an enzymatic transesterification process. It should be kept in mind that the processes are compared as they are today without any attempt to predict further developments of either the enzymatic or the conventional process. The conventional process is a mature and well-developed process, in contrast to the enzymatic process, which is new and immature. We expect that the improvement potential for the enzymatic process is somewhat higher than for the conventional process. This is discussed in the article "Potentials for optimized production of biodiesel in a well-to-wheel study". This article also evaluates other environmental impact categories such as "Land Use" (based on the Recipe and IMPACT2002+ methodologies), "Respiratory inorganic," "Human toxicity (Carcinogenic)," "Ecotoxicity freshwater" (based on the USEtoxTM methodology), and "Aquatic acidification (N)" (based on the EDIP2003 methodology). This article has been submitted to the International Journal of Life Cycle Assessment.

In the above study the "Transesterification process" and "Use of alcohol for producing biodiesel" are used as explanatory variables for response variables such as "Global warming potential" or "Land use". In the event that one (or more) DM(s) are able to influence multiple explanatory variables, it may be interesting to analyze the various explanatory variables that have the potential for improvement on the different response variables and quantify the improvement potential. To enable such an analysis a method has been developed which I have named the "Structural LCA approach" based on "Design of Experiments" (DOE). The "Structural LCA approach" can lead to a large number of unique alternatives of different production methods (and uses). Each alternative we regard as being a pathway (PW): all PWs together form the LCA solution space while any additional PW will increase the LCA solution space. Given that this space is (relatively) large and that several response variables are to be evaluated simultaneously, then this can be characterized as a "multi-objective optimization" problem. A method for handling such a problem has been developed in collaboration with the "Operations Research" group at the Management Engineering department of the Technical University of Denmark. The suggested "Structural LCA approach" and derivative optimization issues are addressed in the article "Enabling optimization in LCA - from the to the Structural LCA approach". This article has been submitted to the International Journal of Life Cycle Assessment. This study also shows that for the production of biodiesel from a WTW perspective the explanatory variable that has the highest improvement potential for the global warming response variable is the "use of straw from the field," which can potentially be a substitute for coal for power generation in a power plant.

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