Results of a test of LCA-software with statistical functionality

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The software test was performed in July to August 1997 on the software-versions available at that time. The work was performed for the Danish Environmental Protection Agency.

The softwares for the test were identified on the basis of being mentioned in the most recent LCA-software reviews (Menke et al. 1996, Rice et al. 1997) as having statistical functionality (mentioned by the reviewers as uncertainty analysis or automatic sensitivity analysis). In addition to these, we identified ourselves a Swedish and a Danish program.

Out of the identified softwares, the following were included in the test:

- The LCV-system of the Danish EPA (beta-version 2.00),
- KCL-EKO of KCL, Finland (version 2.0 for Windows),
- TEAM and TEAMPlus of Ecobilan, France (version 2.0.1.71 and 2.3 r94 with Monte Carlo option),
- PEMS of PIRA, U.K. (version 4).

Some of the softwares originally identified, were not available for the test:

* EPS of Access Scandinavia, Sweden (new version under development, not yet available for testing),
* SimaTool of CML, The Netherlands (not currently on the market).

All 4 softwares were tested on the same computer, a Pentium 200 PC with 16 MB RAM.

The test was made with a simple life cycle assessment, which compares two lubricants, one based on rapeseed, the other based on mineral oil. The life cycle assessment was designed for the specific purpose of the test, i.e. only the most important unit processes and environmental exchanges were included. The case is described in more detail in annex 1.

The assessment criteria were:

1. For which types of data is it possible to enter uncertainties (single exchanges with the environment or other systems, the reference function of a process)?
2. Which format is allowed to indicate uncertainty (variation, intervals, distribution type...)?
3. How easy is it to enter uncertainty information (e.g. is there a default, can data be imported electronically with their uncertainty, what is the time needed to enter uncertainty information)?
4. Which calculation methods are used by the program (simulation?, how many times are the simulation done? how is the reliability of the simulation result documented)?
5. Is the description of the calculation methods in the manual adequate for the user to use the manual as a reference when reporting the LCA-study, or will the user have to document the calculations in addition?
6. For what single results can uncertainty be calculated (single emissions, effect types, weighted data, for one life cycle or for comparisons between more life cycles)?
7. How long time does the calculation take?
8. Can co-variance be taken into account?

9. How is the uncertainty of the result presented?
10. Can data and results be exported electronically together with uncertainties and results of uncertainty calculations?
11. Is it possible to trace back, so that the single contributions to the total uncertainty can be seen in a context? How is this presented?
12. Does the program appear stable?

Assessment of LCV

1. For which types of data is it possible to enter uncertainties (single exchanges with the environment or other systems, the reference function of a process)?
It is possible to enter uncertainties for each single exchange and for the reference functions of processes. Uncertainties can also be entered on characterisation, normalisation and valuation data.

2. Which format is allowed to indicate uncertainty (variation, intervals, distribution type...)?
The coefficient of variance can be entered. Normal or log normal distribution can be selected.

3. How easy is it to enter uncertainty information (e.g. is there a default, can data be imported electronically with their uncertainty, what is the time needed to enter uncertainty information)?
To enter uncertainty is very quick and easy if the coefficient of variance is known for each parameter before modelling the system. To enter uncertainty after modelling is still easy but more time consuming. There is no possibility to set a default for the entire system.

4. Which calculation methods are used by the program (simulation?, how many times are the simulation done? how is the reliability of the simulation result documented)?
Monte Carlo simulation is used and the user can chose the number of simulations. In practice the tested beta version crashed when asked for more than 18 simulations for the test system. The reliability of the simulation result is not reported.

5. Is the description of the calculation methods in the manual adequate for the user to use the manual as a reference when reporting the LCA-study, or will the user have to document the calculations in addition?
The description is not adequate to document the result.

6. For what single results can uncertainty be calculated (single emissions, effect types, weighted data, for one life cycle or for comparisons between more life cycles)?
The uncertainty on the result can be calculated for the entire product system giving a result for every single emission. The uncertainty can also be calculated at the level of effect types, normalised and weighted data. The program cannot calculate the uncertainty on a comparison between systems.

7. How long time does the calculation take?
For the very simple test case 18 simulations took approximately 6 minutes.

8. Can co-variance be taken into account?
If the same process is used several places in a product system, all copies of this process are given the same value in each simulation run. This model-dependent co-variance, which in general is regarded as more important than any real-life co-variance in input variables, is thereby eliminated. Co-variance in external input variables cannot be taken into account.

9. How is the uncertainty of the result presented?
As a table (coefficient of variance) and a graph with confidence intervals.

10. Can data and results be exported electronically together with uncertainties and results of uncertainty calculations?
Yes, in comma-separated files.

11. Is it possible to trace back, so that the single contributions to the total uncertainty can be seen in a context? How is this presented?
No.

12. Does the program appear stable?
No, the beta-version did not give adequate feedback on error messages and crashed without warning when asked to perform more than 18 simulations.

Assessment of KCL-ECO

General background information
All exchanges (named "flows" in KCL-ECO), bot to nature and between processes, are defined in terms of equations relating different inputs and outputs to each other.

1. For which types of data is it possible to enter uncertainties (single exchanges with the environment or other systems, the reference function of a process)?
Uncertainty can be specified for each single equation as well as for an exchange type (e.g. CO_2) for the entire system, thus affecting all equations containing this exchange type. It is not possible to enter uncertainty for allocation, effect type and valuation data.

2. Which format is allowed to indicate uncertainty (variation, intervals, distribution type...)?
Uncertainty values are entered as +/-. From personal communication with the software publisher we know that the system treats such entries as 3 times the spread. The distribution can be selected as normal or uniform. The upper and lower uncertainty limits can be specified differently (they need not be +/- equal percent value).

3. How easy is it to enter uncertainty information (e.g. is there a default, can data be imported electronically with their uncertainty, what is the time needed to enter uncertainty information)?
To enter an uncertainty value for an exchange type (e.g. CO2) of the entire system is very quick and easy.

To add uncertainty to each single equation obviously takes more time. It is not possible to save the entered values and the result of the analysis for each emission (e.g. CO2, SO2, NO3 etc.) unless you save the whole project file under a new name for each emission.

Uncertainty for each single equation may be entered and stored in connection to each process, but this information *cannot* be transferred to the uncertainty calculation. Thus, these values serve as reminders only and have to be entered manually once again when performing the calculations.

4. Which calculation methods are used by the program (simulation?, how many times are the simulation done? how is the reliability of the simulation result documented)?

The program uses simulation and statistical analysis. The number of simulations can be chosen freely by the user (between 100 and 8000). The program offers a choice of two methods for performing the analysis; the Quick method and the Exact method.

The Quick method is much faster than the Exact method. Due to algorithm used in the Quick method, situations appear when the method is not accurate. Because only linear equations are involved, the product system is calculated in each analysis cycle only partially. The errors become significant when the chain of equation is long (over 3 equations) and the uncertainties are large (over +/- 50%).

When the exact method is used, the whole product system is calculated in each analysis cycle. The result is accurate, but the method is slow especially with large systems.

5. Is the description of the calculation methods in the manual adequate for the user to use the manual as a reference when reporting the LCA-study, or will the user have to document the calculations in addition?

The description is not adequate to document the calculations.

6. For what single results can uncertainty be calculated (single emissions, effect types, weighted data, for one life cycle or for comparisons between more life cycles)?

It is possible to calculate the uncertainty of a specific exchange (e.g. carbondioxide) for the entire life cycle, but a separate calculation is necessary for each exchange. It is not possible to calculate the uncertainty per effect type or for weighted data. It is not possible to calculate the uncertainty on a comparison between life cycles.

7. How long time does the calculation take?

Using the exact method, 2000 simulations of the test case took 10-15 sec. for each variable.

8. Can co-variance be taken into account?

Covariance between exchanges cannot be taken into account.

9. How is the uncertainty of the result presented?
The result of the analysis is presented as:

- A list of equations which are included in the analysis
- The original mean value of the analysed parameter
- The mean value of the analysed sample
- The standard deviation of the analysed sample
- The 95% confidence limit of the analysed sample
- A distribution diagram with the frequency distribution of the analysed sample.

10. Can data and results be exported electronically together with uncertainties and results of uncertainty calculations?
No.

11. Is it possible to trace back, so that the single contributions to the total uncertainty can be seen in a context? How is this presented?
No.

12. Does the program appear stable?
Yes.

Assessment of TEAM

General background information
For all exchanges (named "flow" in TEAM), both to nature and between processes, TEAM allows the user to enter not only a value, but also a formula, which may contain both aritmethic, relational, and logical operators as well as mathematical functions and references to other flows or to separate variables. Variables must be defined for each unit process (named "atomic module or node" in TEAM) in which they are to be used. Variables can be defined as "external" and can then be controlled from TEAMPlus for carrying out simulations for different values of the variables.

1. For which types of data is it possible to enter uncertainties (single exchanges with the environment or other systems, the reference function of a process)?
The only type of data for which it is possible to enter uncertainty is external variables. This means that an uncertainty analysis of the entire inventory can only be made if all exchanges (flows) with a large uncertainty are defined as variables (most simply done by giving the mean value as the variable value).

2. Which format is allowed to indicate uncertainty (variation, intervals, distribution type...)?
Only one coefficient of variance (e.g. 10%) can be entered, which is then used for all variables in one set of simulations. Gaussian distribution is assumed.

3. How easy is it to enter uncertainty information (e.g. is there a default, can data be imported electronically with their uncertainty, what is the time needed to enter uncertainty information)?

When carrying out a Monte Carlo simulation where all exchanges (flows) with a large uncertainty are defined as variables, the extra time consumption is the time needed for identifying these flows and defining each of them as a variable.

4. Which calculation methods are used by the program (simulation?, how many times are the simulation done? how is the reliability of the simulation result documented)?

The program uses Monte Carlo simulation. The number of simulations can apparently be chosen freely by the user. The result of each simulation is saved as a file. The result of the simulations can then be analysed further with the function "Statistical analysis" resulting in a minimum, maximum, and mean inventory result (named "ecobalance") with standard deviation, population standard deviation and the relative standard deviation for each exchange type. The reliability of the simulation result is not reported.

5. Is the description of the calculation methods in the manual adequate for the user to use the manual as a reference when reporting the LCA-study, or will the user have to document the calculations in addition?

The Monte Carlo simulation and the statistical analysis are only described in the on-line help of TEAMPlus, not in the paper manual of TEAM. We did not find the explanations in the on-line help adequate to document the calculations.

6. For what single results can uncertainty be calculated (single emissions, effect types, weighted data, for one life cycle or for comparisons between more life cycles)?

To calculate the uncertainty of a specific emission (e.g. carbondioxide) for the entire life cycle, it is necessary to define as variables both the dimensioning exchanges (flows) for each unit process in which the emission occurs, and the actual emissions in these unit processes, and then run a Monte Carlo simulation. Since it is only possible to choose one and the same coefficient of variance for all variables in one run of simulations, it is necessary to select only the most important dimensioning exchanges or emissions as variables and select an average coefficient of variance for these.

This process would have to be repeated for each emission for which the uncertainty is desired. If all exchanges (flows) with a large uncertainty are defined as variables, it is possible to obtain a result for the entire inventory.

It is not possible to calculate automatically the uncertainty per effect type or for weighted data.

It is not possible to calculate automatically the uncertainty on a comparison between life cycles, but the difference between life cycle inventories can be shown and may then be compared to the uncertainty calculated according to the above procedure.

7. How long time does the calculation take?

Calculation of 10 simulations with 3 variables in the very simple test case took 1 minute. However, a lot of time is needed for identifying the exchanges with large uncertainty and defining each of them as a variable, a process which has to be repeated for each emission for which the calculation result is desired. The process will be less time consuming when, for other reasons, all exchanges are already defined as variables when first describing the product system in the database. However, such a general use of variables is complicated by the restrictive naming rules for the variables.

8. Can co-variance be taken into account?
Covariance between exchanges (flows) cannot be taken into account prior to the uncertainty analysis (i.e. on the input variables for the analysis). However, the TEAMPlus includes facilities (named "link analysis" and "correlation analysis") to analyse the result for covariance in the analysed system exchanges (flows) or unit processes based on similarity of exchanges in different processes. These analyses may also be used subsequently to identify major contributing processes and exchanges.

9. How is the uncertainty of the result presented?
.The result of the statistical analysis is presented as a minimum, maximum, and mean inventory result with standard deviation, population standard deviation and the relative standard deviation for each exchange type.

10. Can data and results be exported electronically together with uncertainties and results of uncertainty calculations?
Yes.

11. Is it possible to trace back, so that the single contributions to the total uncertainty can be seen in a context? How is this presented?
No.

12. Does the program appear stable?
Yes.

Assessment of PEMS

General background information
The program does not contain any statistical functionality but allows comparisons between two versions of the same system or between two systems. This is named a "sensitivity analysis" in PEMS.

1. For which types of data is it possible to enter uncertainties (single exchanges with the environment or other systems, the reference function of a process)?
It is possible to enter minimum and maximum values for single exchanges, both to nature and between processes, but when calculating the minimum and maximum results the uncertainties on the flows between processes are not included.

2. Which format is allowed to indicate uncertainty (variation, intervals, distribution type...)?
Uncertainty is given by an interval (average, minimum and maximum)

3. How easy is it to enter uncertainty information (e.g. is there a default, can data be imported electronically with their uncertainty, what is the time needed to enter uncertainty information)?
A default minimum and maximum value is set automatically by the program. This appears to be +/- 10%. We could not find any description in the manual or help function on how to change this default value. The user may alter the automatically set values for each individual exchange.

4. Which calculation methods are used by the program (simulation?, how many times are the simulation done? how is the reliability of the simulation result documented)?
No statistical calculations.

5. Is the description of the calculation methods in the manual adequate for the user to use the manual as a reference when reporting the LCA-study, or will the user have to document the calculations in addition?
No relevant (see above).

6. For what single results can uncertainty be calculated (single emissions, effect types, weighted data, for one life cycle or for comparisons between more life cycles)?
The difference between the results for two systems can be calculated and is presented for each exchange type.

7. How long time does the calculation take?
Not relevant (see above).

8. Can co-variance be taken into account?
Not relevant (see above).

9. How is the uncertainty of the result presented?
The result of the "sensitivity analysis" is presented as a graph showing the difference in percentage for each environmental exchange.

10. Can data and results be exported electronically together with uncertainties and results of uncertainty calculations?
Yes.

11. Is it possible to trace back, so that the single contributions to the total uncertainty can be seen in a context? How is this presented?
Not relevant.

12. Does the program appear stable?
The program is a commercial program in general use. Although we obtained some unexplained errors (the graphical part of the program froze without warning, and when asking for "sensitivity analysis", we obtained an Access error message re. the OLE operation) these are likely to be caused by an incompatibility with the particular configuration of the machine on which the test was performed.

Summary of the assessment

The above assessment is summarised in table 1, where the assessment of the 4 programs is also compared to the standard statistical software-package @RISK (by courtesy of Carsten Lassen, COWI AS). It has not been possible to make a comparison of the results of the analysis of the test case on the 4 programs due to the very different nature of the programs. The results from the LCV and the KCL-ECO programs should in principle be comparable, but the comparison was hindered by the lack of stability in the LCV-program, which did not allow an adequate amount of simulations to obtain a stable result.

Table 1. Summary of the assessment result compared to the standard statistical software @RISK.

	LCV	KCL-ECO	TEAM	PEMS	@RISK
1. Uncertainties can be entered for	Exchanges to nature and to technosphere, characterisation, normalisation and valuation data.	Exchanges to nature and to technosphere.	Exchanges to nature and to technosphere, when these are defined as external variables.	Exchanges to nature and to technosphere. Only the formers are included in calculations.	Exchanges to nature and to technosphere, characterisation, normalisation and valuation data.
2. Uncertainty entry format	Coefficient of variance. Normal or lognormal distributions.	+/-. Normal or uniform distribution.	Coefficient of variance (the same one for all variables!). Normal distribution.	Minimum and maximum value of an interval.	More than 20 distributions including normal and lognormal.
3. Ease of entering uncertainty information	Very easy.	Very easy, but can only be saved by saving the whole project file for each exchange type. Optional default value available.	Time needed to identify major uncertainties and defining these as variables.	Very easy. Default +/- 10% set by the program.	Easy. But the entire analysis has to be modelled in a spreadsheet.
4. Calculation methods and reliability	Monte Carlo simulation. Reliability not reported.	Between 100 and 8000 simulations (either Quick or Exact method). Reliability not reported.	Monte Carlo simulation. Reliability not reported.	No statistical calculations.	Monte Carlo or Latin hypercube simulation. Reliability reported.
5. Description in manual	Not adequate.	Not adequate.	Not adequate.	Not relevant.	Good, but not complete.
6. Uncertainty results	For each exchange type, effect type, normalised effect type or weighted result.	For one exchange type per calculation.	For each exchange type, but based on restricted uncertainty entries (see point 1 and 2).	For each exchange type, but only as a difference between two simulations.	For each exchange type, effect type, normalised effect type or weighted result.

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Table 1, continued:

	LCV	KCL-ECO	TEAM	PEMS	@RISK
7. Time consumption	6 minutes for 18 simulations.	10-15 seconds for 2000 simulations of one exchange type, using the "Exact" method.	1 minute for 10 simulations. Additional time needed for selecting and defining relevant variables.	Not relevant.	The main time consumption is for transferring the analysed system to a spreadsheet, unless the assessment was already made in a spreadsheet.
8. Co-variance of model and input parameters	Eliminates co-variance caused by the same process being used several times in a product system. Co-variance in input parameters cannot be taken into account.	Cannot be taken into account.	Cannot be taken into account, but covariance in the system can be analysed.	Not relevant.	Correlation between any model and/or input parameter can be entered in a correlation matrix.
9. Presentation of uncertainty result	As coefficients of variance and graph with confidence intervals.	As mean, standard deviation and 95% confidence limits of the simulation results as well as a graph with their frequency distribution.	As mean, minimum, maximum, standard deviation, population standard deviation and coefficient of variance.	Difference between two simulations is presented as a graph showing the difference in percentage for each exchange type.	As mean, median, standard deviation and fractiles. Graph with frequency distribution.
10. Electronic export facilities	Yes.	No.	Yes.	Yes.	Yes.
11. Trace back facilities	No.	No.	No.	Not relevant.	Yes, via an analysis showing ranked correlations between output and input-variables.
12. Program is stable in operation.	No (beta-version).	Yes.	Yes.	Probably yes, since it is a commercial program. However, we did encounter some problems.	Yes.

Improvements in the tested programs

The tested versions of LCV and TEAM were non-commercial beta-versions. The software publishers have informed us that the following improvements have been or will be implemented in the first commercially available versions:

LCV:
There will be no restrictions on the number of simulations. The program will be stable and faster than the tested version. The description in the manual will be improved.

TEAM:
It will be possible to select separate coefficients of variance and distribution types for each variable. The reliability of the analysis result will be documented (at least how many simulations are necessary to obtain a stable result). The calculation method will be more clearly described in both on-line and paper manuals. It will be possible to calculate automatically the uncertainty per effect type. Graphical displays will show the min-max and 5-95 percentile intervals for each exchange or effect type.

Furthermore, the publishers of PEMS have informed us of the following planned improvements for future versions: The maximum and minimum results will include the uncertainties on the flows between processes. The user will be able to select a combination of maxima and minima to be used in the calculations.

References

Menke D M, Davis G A, Vigon B W. (1996). Evaluation of life-cycle assessment tools. Ottawa: Environment Canada, Hazardous Waste Branch.

Rice G, Clift R, Burns R. (1997). LCA software review. Comparison of currently available European LCA software. International Journal of Life Cycle Assessment 2 (1):53-59.

Annex 1. Description of the test case

The test case description is not available in electronic format. Requests should be directed to Christine Molin, Institute for Product Development <cm@ipt.dtu.dk>.