EFORWOOD

Sustainability Impact Assessment of the Forestry - Wood Chain

Project no. 518128

EFORWOOD

Tools for Sustainability Impact Assessment

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PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	X
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Summary

This report is project deliverable PD4.2.4 of the EFORWOOD project.

The first part of the report describes general benchmarking theory. Then, some features and requirements for benchmarking indicators are given. The case study part of the report presents very diverse types of benchmarking cases – four wood based products industry and one from paper industry.

The main conclusion of the report can be summarised as: *the big picture matters; a pattern must be evaluated as a dynamic whole.*

The contents of this work is intrinsically linked with the future work on response functions in work packages 4.2 and 4.3 as well as in M1, the development and interpretation of ToSIA.

This report is a joint work of Technical Research Centre of Finland (VTT), Building Research Establishment (BRE) and Pöyry Forest Industry Consulting.

Summary

Contents

1 INTRODUCTION

This report belongs to European Commission's EFORWOOD project, contract number 518128-2. Module 4, who is responsible for this report, is a partnership of European companies focusing on the manufacturing and processing ("gate to gate") stage of the Forestry Wood Chain (FWC) in Europe. This document is a project deliverable PD 4.2.4. and it examines benchmarking options for companies and regions, national and European level, across the manufacturing forestry-wood-chain and throughout Europe.

The nucleus of the problem is the desire to measure the environmental performance of an entity, be it a project, a product, a mill, an organisation, an industry, an industry scenario, a process, an ecosystem or something in a very wide sense comparable. What is sought is generic excellence (Spendolini 1992) whatever the performer or the field. A further common characteristic is the need to *measure, compare and improve* the environmental performance discussed.

In the first part of this report, general benchmarking theory is described. In Chapter 3, some welcomed features and requirements for benchmarking indicators are listed. In the case study part, very different types of benchmarking cases are presented. Four of the cases are form solid wood and wood products chains and one of them is from paper industry. The report illustrates the variety of possibilities in environmental benchmarking.

The information in this report is essential for the future work on response functions in work packages 4.2 and 4.3. In addition, the range of possibilities and need of tailor-making in environmental comparisons and benchmarking should be kept in mind in M1, the development and interpretation of ToSIA. In some parts, this work links to also Delivery 4.2.2 "Report on review of existing tools".

This report is a joint work of Technical Research Centre of Finland (VTT), Building Research Establishment (BRE) and Pöyry Forest Industry Consulting.

2 ENVIRONMENTAL BENCHMARKING THEORY (PÖYRY)

2.1 Problems in Environmental Assessments

In the following, some typical questions raised in environmental assessments are enumerated (Vasara 1999):

- *What are the environmental effects of the production of a tonne of newsprint from the perspective of the entire life-cycle of the product?*[1]
- *How can environmental impact assessments for two alternative implementations of a pulp mill project be compared?*[2]

[1] Life Cycle Assessment (LCA)
[2] Environmental Impact Assessment (EIA)

- *Biodiversity is protected by the Rio Charter, but how can biodiversity in a forest be measured and cultivated?*[3]
- *How can the sustainability of different pulp and paper industry scenarios be compared?*[4]
- *How can the performance of pulp and paper mills seen as a whole (incorporating environmental, technical and economic aspects) be measured and improvement made?*[5]

The questions are formulated as pulp-and-paper-industry-specific, but that need not be the case. For some of the questions above there are established ways to produce answers. Yet, there is a marked difference between established method and best practice.

The nucleus of the problem common to all these is the desire to measure the environmental performance of an entity, be it a project, a product, a mill, an organisation, an industry, an industry scenario, a process, an ecosystem or something in a very wide sense comparable. What is sought is generic excellence (Spendolini 1992) whatever the performer or the field. A further common characteristic is the need to *measure, compare and improve* the environmental performance discussed.

2.2 Solutions from a Framework: Environmental Adaptive Benchmarking

In trying to gain an insight into the tapestry of environmental assessments, a unified framework is of the essence. It is to this end that the Environmental Adaptive Benchmarking (EAB) framework is presented (Vasara 1999). Environmental issues are often highly cross-disciplinary, and this is reflected in EAB. Simultaneously, the adaptive benchmarking concept is not bound to environmental issues and can be used for any improvement process.

How, when, and why do we attempt to weave together environmental issues, benchmarking and adaptation? *Continuous improvement is a common theme for benchmarking and adaptation, and continuous improvement is an inescapable need in environmental issues.*

On the other hand, adaptation deals with *processes where a structure is progressively modified to give better performance in its environment.*

A definition for benchmarking, from the field of business management, is the following:

> *a continuous, systematic process for evaluating the products, services, and work processes of organizations that are recognized as representing the best practices for the purpose of organizational improvement* (Spendolini 1992).

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[3] Biodiversity measurement and management

[4] Sustainability Analysis (SA)

[5] (Total) Environmental performance

Application Areas

Analogously to the limited definitions of applicability for environmental assessments such as LCA, some (e.g. Laamanen 1993) see benchmarking and auditing being applicable only to processes, and quality awards to entire companies (Vasara 1999). This type of restriction, along with the limitations on the use of environmental assessments, does not fit within the EAB framework. In fact, benchmarking has not been limited to strict manufacturing:

- staff performance (Fitz-enz 1994),
- public sector performance(Valve 1994),
- research and development (Bendell 1993), (Coplien 1994)
- legislation and taxation (Hameri 1994); (Simons Consulting Group 1994)

are examples of applications.

Hybrid Frameworks - a Concise SWOT Analysis

There are, obviously, hazards and limitations in using a multi-disciplinary, hybrid approach. Thus, a concise SWOT-analysis (Strengths, Weaknesses, Opportunities, Threats) can be used to crystallise the essentials. The perils of hybrid frameworks are illuminated directly by EAB flaws. Let us assume here that the EAB framework as an hybrid is an organism and look at its characteristics. The quick-and-dirty-SWOT is performed by taking the definition of a hybrid, splitting it into its component parts and analysing the corresponding EAB characteristics and the S, W, O and T for each.

Figure 2-1
SWOT of the Hybrid Framework Aspects of EAB (Vasara 1999)

What to Benchmark

A remark attributed to an IBM expert: "Anything that can be measured can be benchmarked" is often repeated in benchmarking literature. There is an earlier precedent "Measure what can be measured, and make measurable what cannot be measured" (Galileo Galilei). However, benchmarking is often especially useful in areas where the measurement is especially difficult. The remark takes a slightly illogical turn to "Anything that can be benchmarked can be measured".

Spendolini (1992) lists the following examples of things to benchmark:

– products and services (provided and used)
– processes
– support functions
– organisational performance (costs, revenues, production, quality)
– strategy

Tendencies noticeable e.g. in (Watson 1993) are

– more abstract benchmarking (e.g. strategy)
– more global benchmarking application

Both these tendencies fit in with the EAB concept. What EAB implies is that we benchmark ways of doing things, or analogies for ways of doing things. Examples can be sought in one's company, one's industry, all industries, human endeavour, the history of human endeavour, nature - or a Platonic ideal world. ‘The Platonic’ is in this section used to denote a type of comparison to an ideal in a manner transcending mere measurements. As Plato had very little regard for measurement as opposed to philosophical thought, he would assuredly not have enjoyed an activity such as benchmarking.

The benchmarking process itself should be continuously improved - by benchmarking.

How to Benchmark

Classifications of different kinds of benchmarking are numerous. Watson (1993) presents his "five generations of benchmarking":

– First Generation: Reverse Engineering
– Second Generation: Competitive Benchmarking
– Third Generation: Process Benchmarking
– Fourth Generation: Strategic Benchmarking
– Fifth Generation: Global Benchmarking

As a possible sixth generation of such an evolutionary view of benchmarking, *evolutionary or adaptive benchmarking* might perhaps have a place.

The Focus Dimension of Benchmarking

Usually, only one dimension is used in benchmarking overviews, and this most closely corresponds to it. In the Karlöf & Östblom (1993) grouping, only three categories: internal, external and functional exist.

– Internal: comparison of activity within the company. Thus, *nosci te ipsum* - "know thyself" and thy processes
– External: comparison with similar activities outside the company. Thus, know your surroundings.
– Functional: comparison of the activities of one's own company to activities deemed excellent regardless of industry. Thus, know best practices.

In the categorisation used by e.g. Camp (1989), the two latter categories overlap.

– The Karlöf "external" becomes the Camp "competitive" (against best competitors) and "functional" (against best in industry, competitors or not)
– The Karlöf "functional" becomes the Camp "functional" and "generic" (against best in any industry)

Dr. Jim Crilley of Unilever produced the following division (see Bendell 1993):

– Internal: better than we have done before
– Competitor: better than anyone in the industry
– Worldclass: better than anyone else
– Customer: better than customer expectations

which meshes with the Camp definition and adds a new level in the *customer*. Camp mentions "extended benchmarking" when discussing end user defined requirements. Here, benchmarking in EAB is extended with some new definitions. The EAB focus categories arrived are

- oneself (e.g. internal)
- one's industry (e.g. competitor)
- human endeavour (e.g. any industry)
- phenomena (anything, any time, any place)

The extensions attributes include

- Strategic: used by Watson (1993) as the fourth generation of benchmarking; using a better strategy than anyone/anything

- Historic: better than anyone/anything else ever

- Nature: better than anyone/anything in nature

- Shadow/echo/sonar: having a better shadow/echo/sonar image than anyone/anything. This points to an evaluation where different types of *projection* (e.g. shadow, echo, sonar image) are used as the measure of something. At its simplest: only one component of a 2-d vector is used. At a more complex level: the pattern left by an activity in a thermal scan is measured against a library of reference patterns.

- Heuristic/algorithmic: using a better heuristic/algorithm than anyone/anything. We could e.g. benchmark the sorting activity at a plant by the sorting algorithm used - every engineering student has or should have run across the basic comparisons of e.g. quick sort, bubble sort and other standard algorithms. The algorithm can be as complex or simple as desired.

- Topology: striving for the topology of the best performers' performance. Comparison at an admittedly and intentionally high level of abstraction: we can use e.g. a projection that preserves the topology. To give a simple example: if two vectors are close to each other in n dimensions, such a projection to 2 dimensions situates them close to each other in 2. Thus, we can project complex patterns from n dimensions, see what their topology is, rate the best performers and aim at having the same topology as these references.

- Ideal: as well as it can be done at all; as well as can be thought possible; against a Platonic, theoretical ideal, or one construed as a suitable yet unreachable goal to strive for.

To conclude this section on a more philosophical note, the use of the *topology* of a problem in benchmarking presents itself. To wit: we have a problem, and a group of solutions to it. These solutions can be depicted as vectors in n-space. These vectors are projected to a self-organising map (SOM). Certain solutions are on the map forced to certain points, and the others form a pattern. Now, the question becomes: find a problem with a similar solution topology, or rather, adapt a certain problem to have a similar solution topology.

The Time Dimension of Benchmarking

Benchmarking in practice has so far has been both dynamic and static. Dynamic in that it has an inbuilt imperative of continuous improvement, static in that it also seems to have an inbuilt imperative of continuous progress in time, i.e. that the best solutions are always found in the future, not in the past. Time has been used as a benchmarking measure, but only in benchmarking time, not *against time*. That is, benchmarking with e.g. the through put time as an indicator, not benchmarking against others on a time axis.

For the types of benchmarking focus, the time dimension can be added to practically all terms. However, to preserve the current usage of most, EAB extensions such as *ideal, nature, topology, heuristic* are defined as incorporating the time dimension.

Key Benchmarking Algorithms

Different sources and uses have different algorithms for the same basic function. Below, a list of key algorithms in benchmarking history:

- Frederick Taylor's scientific method: Plan-Do-See
- The Shewhart/Deming cycle: PDCA Plan-Do-Check-Act
- The Dewey algorithm for learning: discover new insights, invent new possibilities, produce action, observe the consequences
- The American Productivity & Quality Center (APQC) Benchmarking Four Phase Model: Plan the Study, Conduct the Research, Analyze the Data, Adapt, Improve and Implement Findings
- The XEROX manager-change integrator LUTI: Learn-Use-Train-Inspect

Algorithm for Genetic Optimisation

The basic algorithm for *genetic optimisation* can be used as the adaptive plan. An initial population of possible solutions is first created. Then, a loop continues until predetermined end criteria are met. In this loop the fitness of all individuals in a solution population is evaluated and a new population created.

Generic Adaptive Benchmarking Algorithm: Recognise-Position-Adapt

In this presentation of the EAB concept, the data collection phase has been purposely faded into the background - data is needed and must be collected for the other phases to function. Analyse, adapt and improve are most definitely present in

- Recognise
- Position
- Adapt

EAB Summarised

As a field of study, management is eclectic, drawing upon a variety of theoretical frameworks. The mathematical element brought in by a fusion with adaptive systems theory results in a hybrid.

What happens in environmental adaptive benchmarking?

1. There is a goal: a specific task of improvement, implemented through the sequence *recognise, position, adapt*.

2. There is a virtual *environment*, a testing ground chosen for the particular task and entity. This virtual environment can be said to function as a virtual receiving environment that is geared towards giving very specific feedback.

3. There is an *n*-dimensional index of performance, a *fitness*, to measure the improvement.

4. There is a plan of *adaptation* to make the improvement process systematic.

2.3 The Human Factor

On the surface, the emphasis on mathematics and technological possibilities in benchmarking might indicate an absence of the human factor. However, the human factor is very much present indeed, in form of e.g.

– Incomplete information(imperfect knowledge, imperfect world)
– Subjective valuations
– Trade-offs and conflict
– Optimal compromise

3 FEATURES AND REQUIREMENTS FOR BENCHMARKING INDICATORS (VTT AND BRE)

Some welcomed features and requirements for benchmarking indicators (BI) are listed below.

1. BI values are not constant. BI values changes according to the changing business and processing parameters

2. BI:s provide quantitative data, information and knowledge

3. BI:s may need to be supported by qualitative information

4. BI:s helps in the identification of the most appropriate improvement options

5. BI values can be measured, determined and reliably evaluated

6. BI can be used in short and long term assessment and planning

7. BI may have positive and negative movements

8. BI reflect the situation in upper level and lower levels – accuracy or level of detail may vary

9. BI are not very sensitive

The indicators and benchmarks can then be used for:

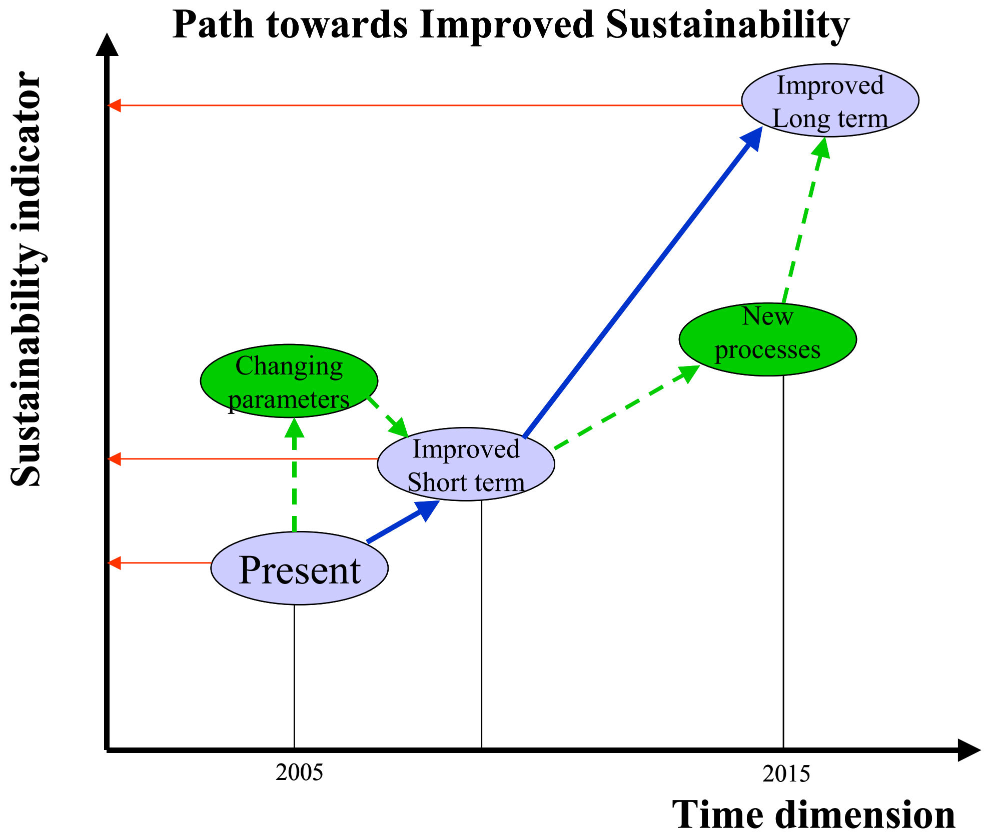
- Setting of targets
- Comparison of performance at a site, company, regional and national level
- Estimation of waste & other impacts throughout a project/to a time period (e.g. a year)
- Set as contractual clauses/conditions for a project or business (e.g. conditions of business agreed between partners to improve business)
- Provide data for the need for local and regional facilities and in bids/tenders/proposals to win a business

To participate in a benchmarking exercise can bring the following benefits:

- Be able to set realistic and attainable environmental/economic/social targets
- Know exact figures that can be comprehensively analysed in business planning
- Improvement plans can have a sound basis
- Measurements of improvements can start
- Financial savings can occur
- Help win tenders through sustainability commitments
- Be able to meet clients requirements of sustainability commitments (and/or national requirements for best practice)

The short and long term paths towards improved sustainability are shown in Figure 3-1 below. An assessment of values of sustainability indicators provides a reference line in relation to current practice within manufacturing and business processes. By manipulating selected conversion parameters it is possible to improve the system and manufacturing processes and therefore contribute to achieving improvement of sustainability in short time. However the major improvements can be reached through investments and by implementing ‘advanced technical solutions’.

Figure 3-1
Short- and Long-term Paths towards More Sustainable Forest Industry



In short the term, it is not possible to achieve significant changes in business or in processing that will consequently effect indicator values and therefore sustainability. This means that the gradient is rather small. Anyway, in the long term, radical and innovative changes are possible. The gradient is considerable bigger. Benchmarking Indicators (BIs) are therefore important in selecting the most appropriate processes for quick-wins for short-term improvements as well as for long-term developments for finding paths towards more sustainable industry.

A set of benchmarking indicator vectors represent the impacts of changes in business and processing, Figure 3-2. The figure illustrates the influence of changes on indicator values. The starting point of indicator is set the same in the relative co-ordination system. The set of vectors starting from the origin – current situation - are directing towards higher or lower positions. In some cases, significant positive improvements are achieved however in some case sustainability and corresponding indicator values can be decreased.

Figure 3-2
A Set of Benchmarking Indicator Vectors Represent the Impacts of Changes in Business and Processing

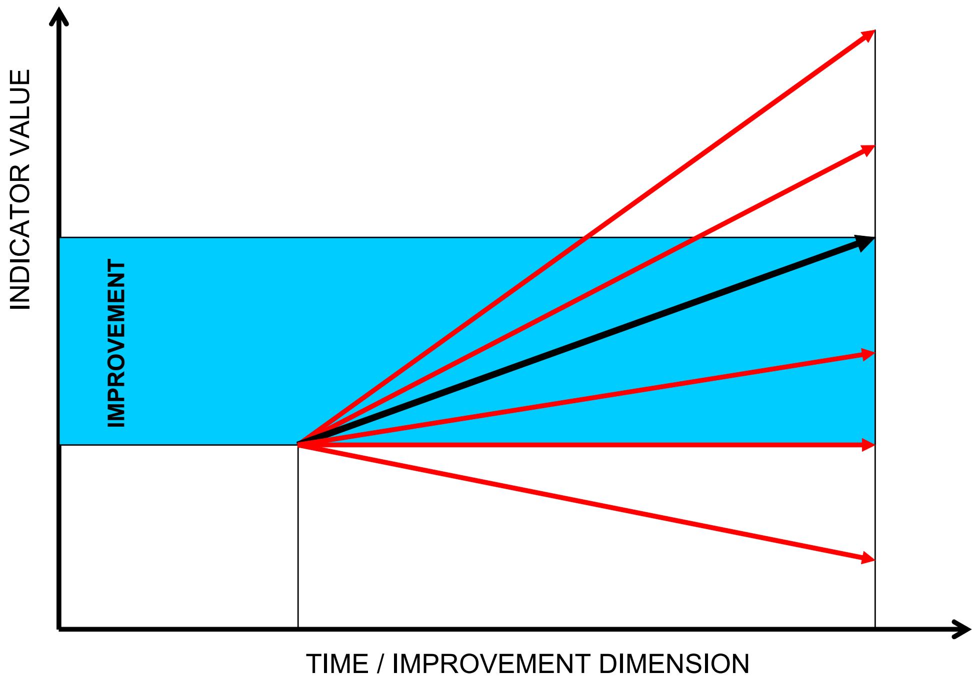
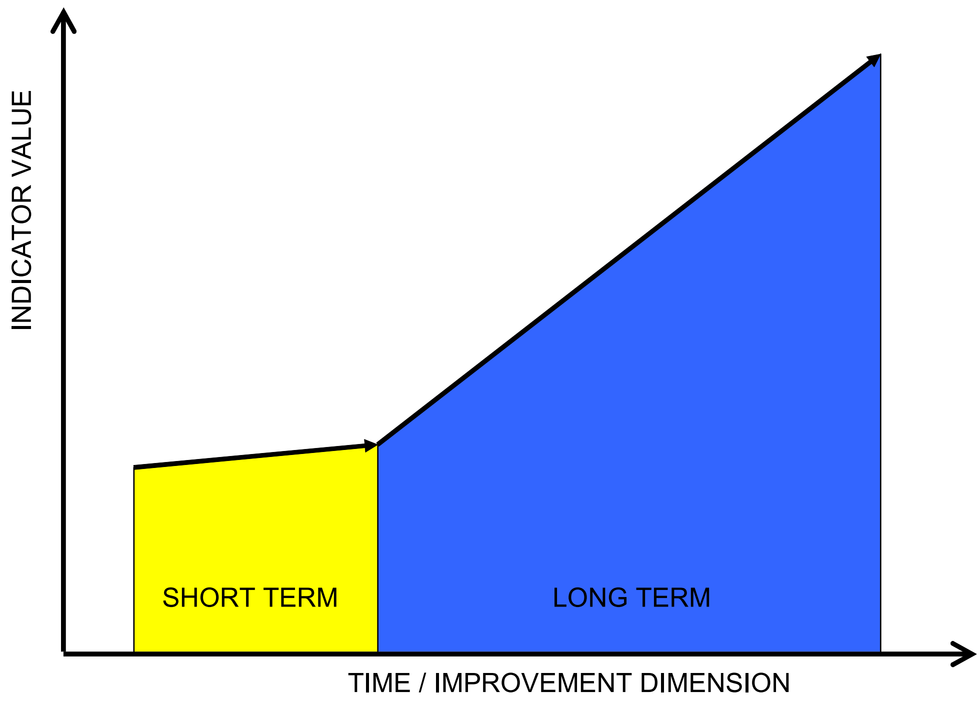


Figure 3-3 illustrates weighted, average short and long term vectors that represent the total impacts of changes in business and processing. The principal question is now how to determine and describe the total impact instead of set of single vectors or indicator values. Total impact is described in Figure 3-3 with the aid of two weighted "average" vectors: one for short term and the second one for long term. This provides fundamentals for assessing and comparison between several potential improvement options.

Figure 3-3
Weighted, Average Short- and Long-termVectors Represent the Total Impacts of Changes in Business and processing



4 BENCHMARKING CASE 1: WOODSIM (VTT)

Following are relevant indicators for benchmarking. People from the industry are interested to get information of indicator values in order to positioning them on the map.

Indicators – Economics

1. Cross value of the production per product unit (i.e. €/m^3 , €/piece)
2. Cross value of the production per wood raw material unit (i.e. €/m^3 , €/piece)

3. Net value of the production per product unit (i.e. €/m^3 , €/piece)
4. Net value of the production per wood raw material unit (i.e. €/m^3 , €/piece)

5. Value addition = value of the production minus price of the incoming semi finished material per product unit
6. Value addition = value of the production minus price of the incoming semi finished material per incoming material unit

7. Price of wood raw material at the mill (€/m^3)
8. Labour costs per product unit (€/m^3)
9. Total costs per product unit (€/m^3)

Indicators – Efficiency

1. Annual turn per number of people
2. Annual turn per investment costs

3. Annual production number of people
4. Annual production per total working hours

5. Volume yield from the amount of wood raw material (%)
6. How many cubic meter wood raw material is needed for manufacturing one cubic meter products

7. Energy (electricity and heat) consumption per raw material and product cubic meter

The values of these indicators can be received of companies' statistics. Industrial associations are also gathering corresponding data thus providing reference values country wise. Summarising data figures on European level can also be established.

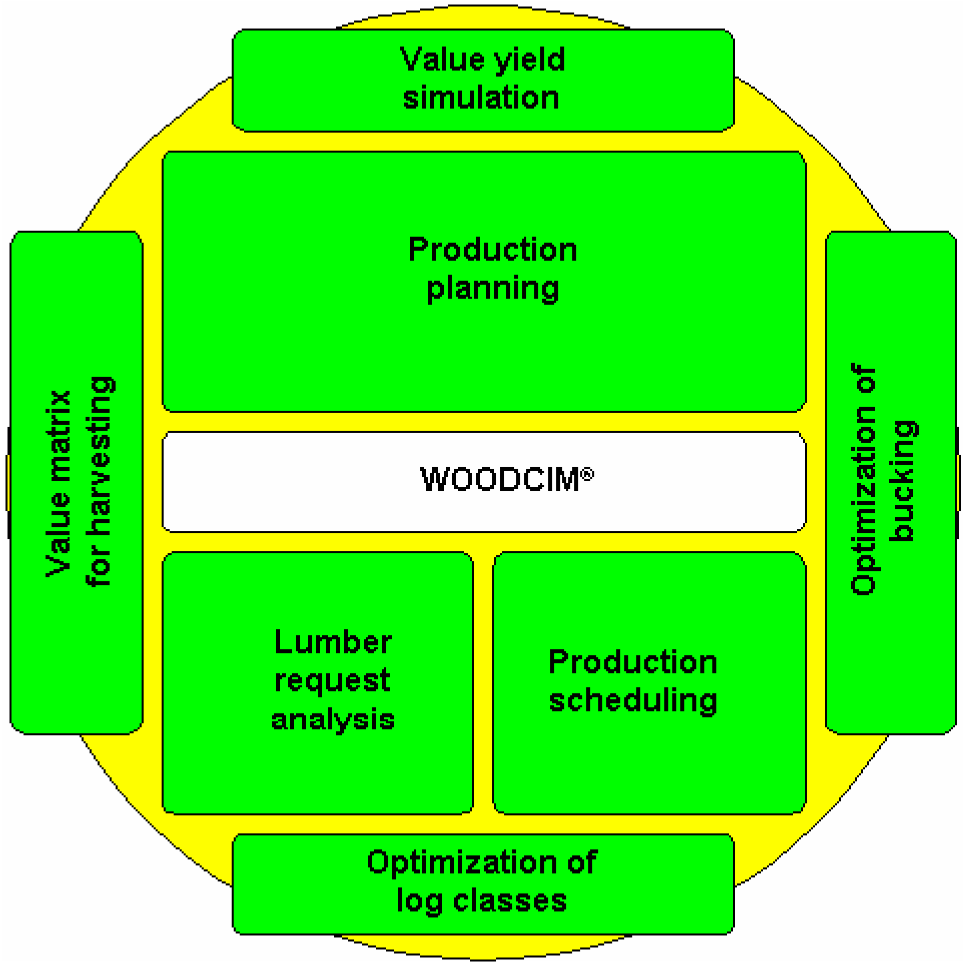
VTT has developed **WoodCIM®** model and software system for providing information and knowledge concerning how to optimise activities throughout the conversion chain from the forest to the end products and how to improve business and processes. The model system consists of precise description of wood raw material, manufacturing processes and markets and products. In the following systems is described.

WoodCIM® Integarted software system supporting decision making for saw mills and benchmarking options

WoodCIM® is a model and software system developed by VTT Technical Research Centre of Finland. The system describes the whole conversion chain from the forest to the end products. It is comprised of the following integrated software modules (Figure 4-1):

- Simulation program for predicting the volume and value yield by sawing a log or a log class
- Program for optimising the limits of sawlog classes
- Sawing model based on linear programming for planning of production, harvesting and marketing
- Model and software for optimisation of value added components
- Integrated optimising model "from stump to final product", supporting bucking operations

Figure 4-1
WoodCIM® Consists of Integrated Software Modules



The **WoodCIM®** system can be linked to the product and material flow control system or other information systems at a sawmill, producing and transferring updated information for planning. **WoodCIM®** will in turn return information to be delivered to different phases of business operations.

The different modules of the integrated software focus on maximising profit or value yield, taking into consideration non-homogenous wood raw material, variation as well as the process and market variables. The program system operates in a PC-environment and provides by a user-friendly computer interface. The interface software contains a module for checking the correctness of input data. The software modules also allow creation of different scenarios, i.e. theoretical production lines and products, which allows studying their potential profitability.

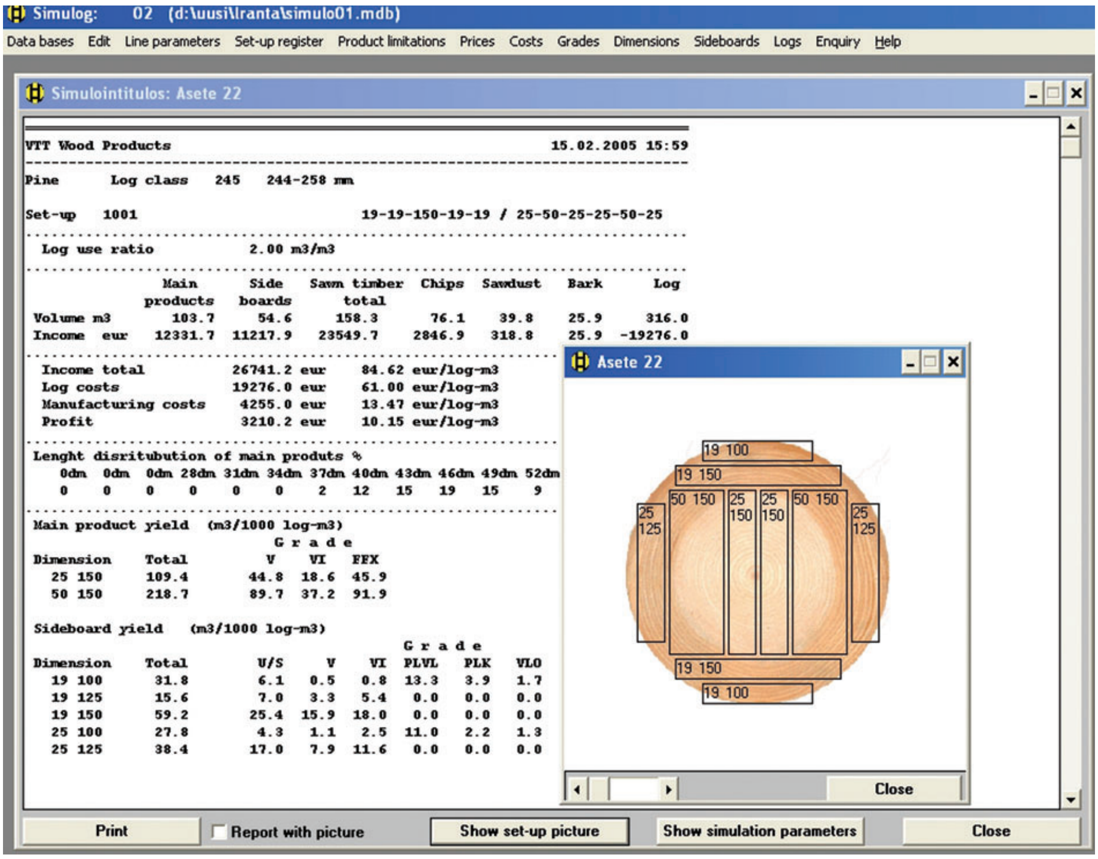
WoodCIM's® modules:

Simulation software for predicting the volume and value yield for sawing set-ups

The simulation model mathematically "saws" the log or log class into sawn timber pieces by grades according to the end-users' specific needs, chips and sawdust. The best blade settings and patterns for each log class are determined by simulations. Sawn timber pieces or flitches can be further converted into components in order to optimise the secondary conversion process.

The simulation program contains a description of the log and log class, sawing process, factors affecting the value yield and potential sawn timber products. Description of the log class involves the determination of individual logs as objects of calculation. The mathematical description of each log can be divided into two components: description of the log shape and internal features. Input data on raw material quality can be provided by the sawmill's statistics, through trial sawing or automatically by the scanning of the internal features of logs using i.e. X-ray systems. Using the trial sawing method combined with statistics allows the creation of mathematical quality distribution functions capable of predicting the probable quality distribution percentages of lumber pieces cut from a certain segment of the log.

Figure 4-2
Examples of Output Data Windows in the Sawing Simulation Software



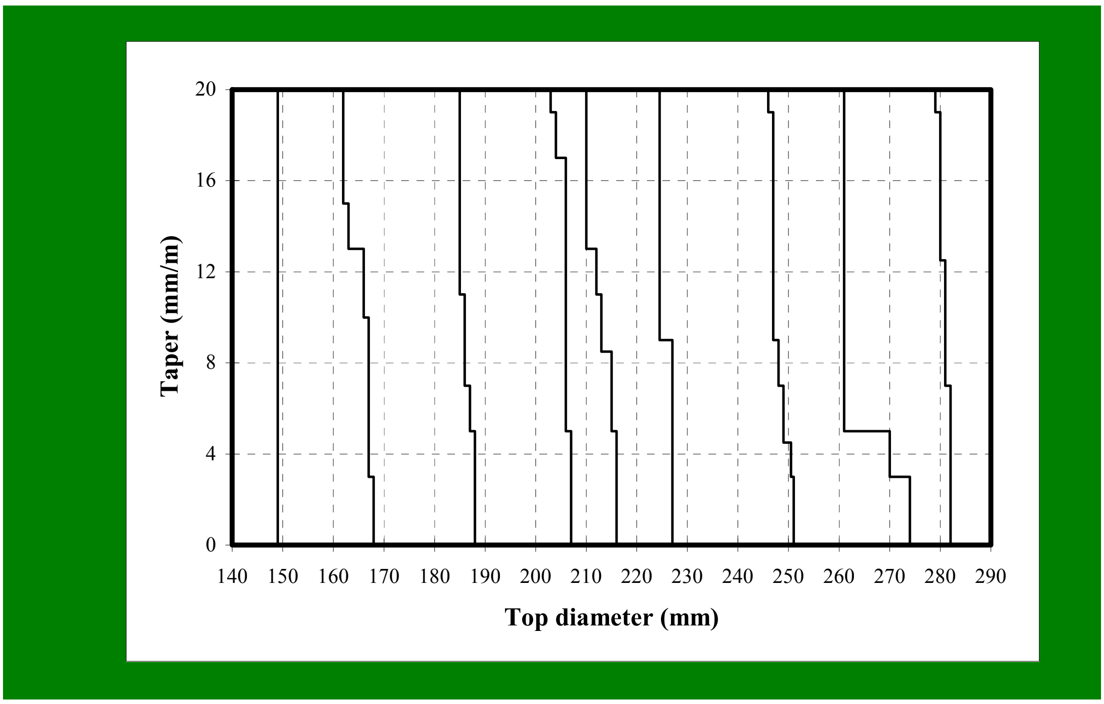
The input data for the simulator includes details of sawlog properties, nominal and green dimensions of sawn goods, sawkerfs, and prices of sawn timber by dimensions and grade, grade distributions of heartwood sawn timber and side boards allowed in sawing. The input data are based on information obtained from research on wood raw material, sawing processes and products and of the statistics from sawmills. The prices used in the simulation are usually based on existing sales prices.

The software creates as output data (Figure 4-2) the dimensions (thickness, width) and lengths by grades probably achieved in sawing. The computer also calculates on the basis of the input data a certain number of economically best blade setting alternatives for a sawlog or sawlog class. It is also possible to calculate the log sizes that give optimal production of heartwood lumber.

Program for optimising the limits of sawlog classes

In many countries logs are normally sorted into log classes. Each of log classes are sawn using fixed blade settings. This means a much higher capacity compared to the sawing operation where the blade setting can be changed individually for each log. Sorting criteria are log characteristics like wood specie, top diameter, quality, length, taper and sweep.

Figure 4-3
The Limits of Log Classes Top Diameter and Taper as Sorting Criteria (Example)



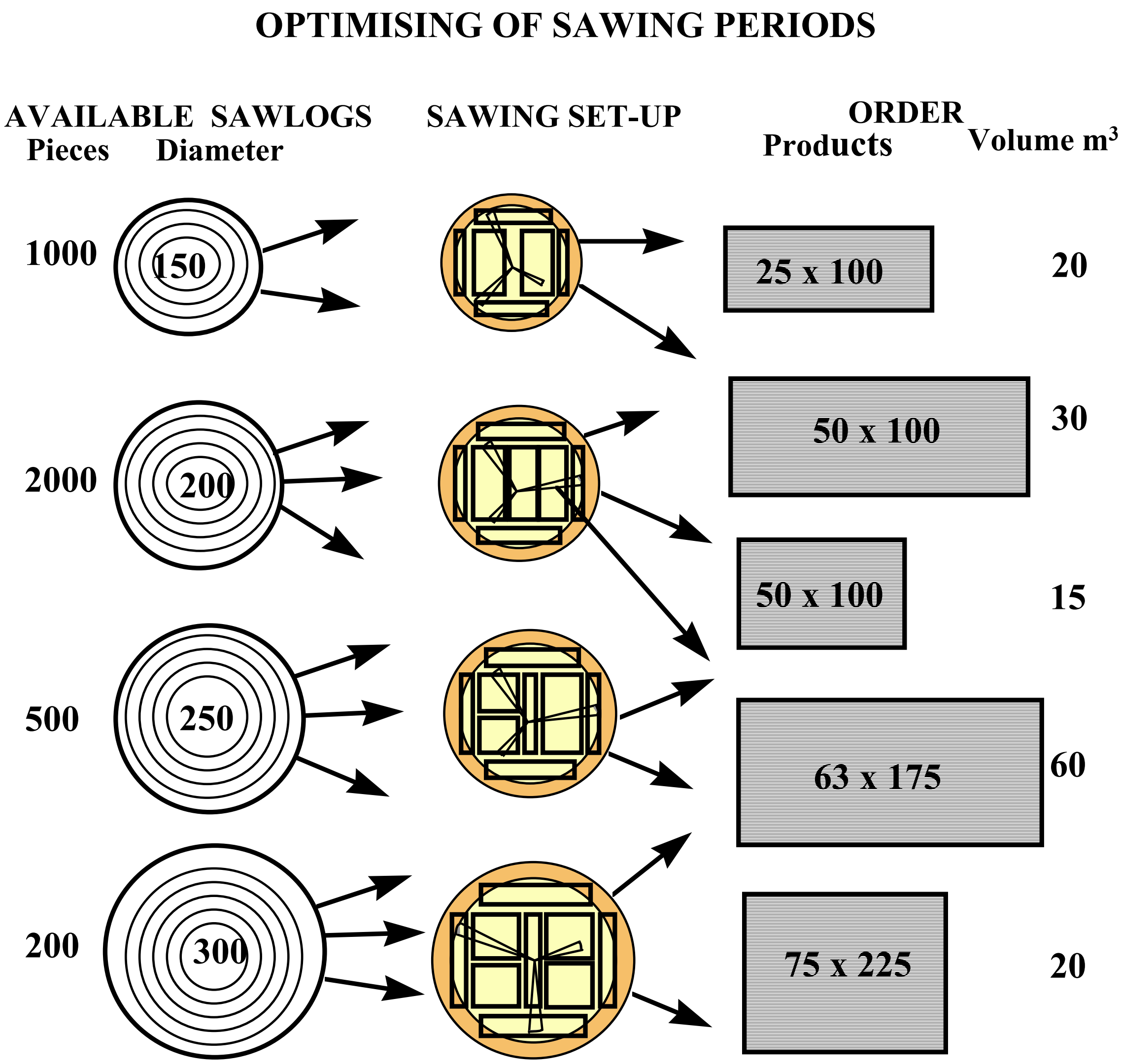
The **WoodCIM®** optimisation software for log sorting requires as input data the volume and value yield figures produced by sawing simulations. Additional inputs include the sawn timber marketing factors, demand and prices as well as end-users' requirements. The model produces a number of best sorting alternatives and best blade settings for each log class. An example of optimised log classes is illustrated in Figure 4-3.

In the optimising software a log distribution is presented in terms of element logs with top diameter increment of one millimetre. Each element log is described in terms of criteria to be used in the sorting and proportion from the total number of logs. The number of log classes cannot exceed the number of sorting bins.

Optimisation software based on linear programming supporting planning of production, harvesting and marketing

The optimum sawing strategies for a time period(s) (one month, for instance) can be drawn using an optimisation model based on linear programming (Figure 4-4). The goal is to achieve the best profitability for sawing periods. The possibilities of using the best blade setting for a sawlog class are often restricted. There are always sawn timber dimensions and grades having only limited demand on the market. In contrast, when the demand is high the desired product has to be sawn from several different classes. The **WoodCIM®** sawing model optimally combines the log supply, sawing possibilities and sales.

Figure 4-4
The Objective in the Optimization of Log Classes is to Combine the Orders and Available Logs together Yielding Maximum Value Yield and Profit



Input data contains details of log supply (available logs), yield factors produced by set-up simulation, orders and sales potential, product prices and capacities of production lines during the time period to be planned. The software estimates the profit for the time period, the number of sawlogs to be sawn using a certain set-up, the number of sawlogs to be left in storage and the product assortment (dimensions, lengths and grades) to be manufactured. Shadow Price-analysis results in valuable information to management.

What are the benefits of using WoodCIM®?

This software is used in advanced planning at many Finnish sawmills. Computer aided planning of sawmilling activities has yielded good results. It has been possible to increase the sales value of the production considerable compared to less sophisticated planning methods. Using the integrated and optimising approach provided by **WoodCIM®** allows its industrial users to increase value recovery by taking **a competitive advantage** in:

- active management and control of **procurement of wood raw material**
- optimally combining the available wood raw material **to market demands and orders** of wood products
- dynamic promotion of lumber **sales and marketing**
- management and control of production chains - processes as a whole in order to achieve the best possible **value yield**, minimum **through put times** and minimum **inventories in the chain**,
- improvement of the **added value of the products.**
- tracing options for improvement of business and processes

By using **WoodCIM®**software in the planning operations, sawmills can dynamically manage and control all of the conversion related procedures. By comparing the realised output with the plans, a user can create fast new plans and start the corrective actions immediately, if necessary. Need for changing the plans is usually based on changes in the lumber market and orders or changes in the quality or size of wood raw material. In computerised planning and control, the computer quickly calculates new plans, providing the management and designers relevant information to make the right decisions. By comparing different plans and alternatives, it is possible find the way towards improved profitability. Computer-aided planning can produce fast new solutions, however the final decisions are always are made by people.

WoodCIM® for calculation of benchmarking indicator on company level

A company who wants to trace how to improve business or manufacturing processes can proceed as follows.

1. **WoodCIM®** is provided with input data from the company and manufacturing facilities.
2. Primary simulations and optimisation procedures are executed and the output recorded.
3. The output is compared with the information from the statistics and other data sources. The analyses provide base for continue.
4. The indicator values are compared with the available national or European value distributions and the results evaluated.
5. The plan for potential improvement options will be prepared based on the evaluation results.
6. The improvement options are converted into input data for **WoodCIM®** simulations. The simulation runs are executed. If there is a need 5 and 6 are repeated.
7. Based on the results realisation plan for improvements are compiled.
8. Realisation procedures are executed

WoodCIM® for calculation of benchmarking indicator on national and European level

The principal approach is the same as for company level. For the analyses a representative set of companies or mills should be selected. Each company has it's weight in the calculations for national and European level. Anyway country and European level figures can be calculated. It can be estimated large variations between companies. It may be difficult to identify some average improvement steps towards more sustainable industry.

Better and more realistic results can be achieved through providing information and knowledge from carefully selected case studies.

5 BENCHMARKING CASE 2: DEMONSTRATING THE ENVIRONMENTAL ADAPTIVE BENCHMARKING WITH A NEWSPRINT – LCA (PÖYRY)

In this case, demonstrating an environmental adaptive benchmarking (EAB), the goal is to improve the environmental impacts of newsprint production on a national level. Do this using both national - level and mill - level measures. In the analysis, use scenario analysis combining waste disposal, production technology, energy production and transport options (Vasara 1999).

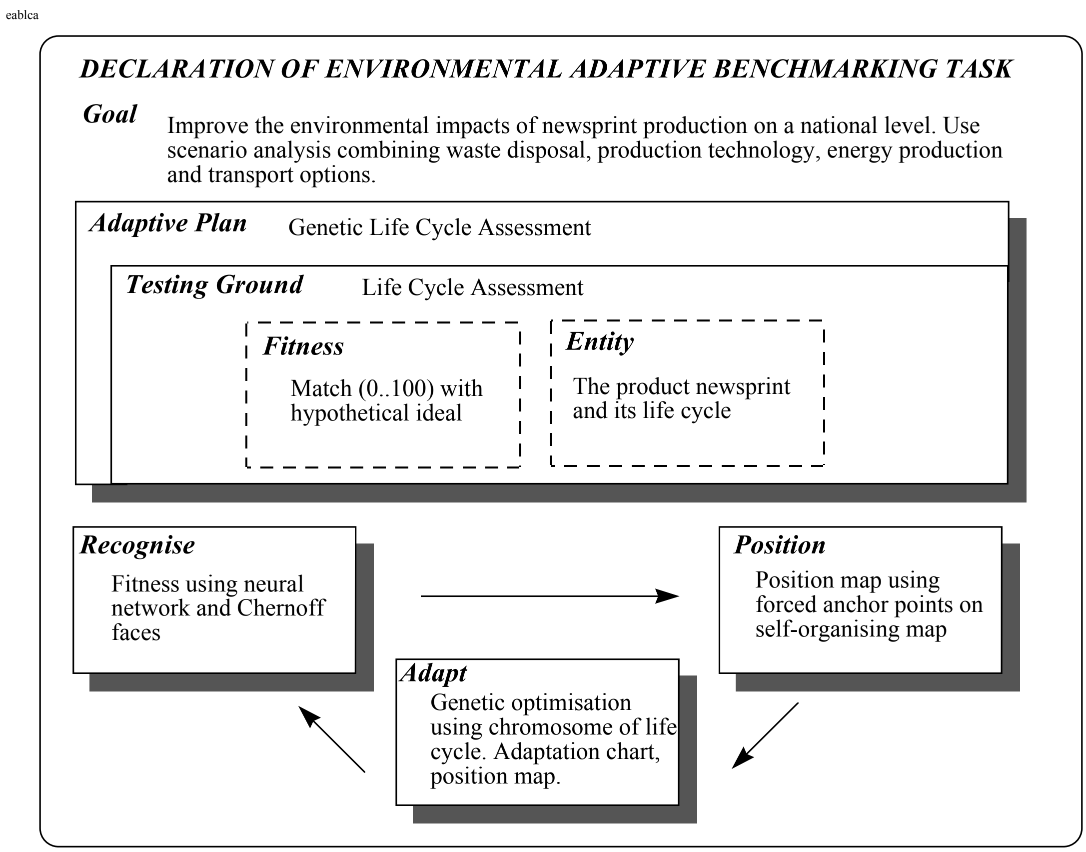
The benchmarking is carried as EAB. The sequence Recognise/Position/Adapt (Please see Chapter 2) in this EAB LCA or genetic LCA (GLCA) functions as follows:

- Recognise: Use the *inventory* phase to produce a snapshot of the current state. Use *valuation* to produce a fitness.
- Position: Use a test suite/reference grid of inventories/other states to position current state (projection from *n* dimensions to 2-3)
- Adapt: Implement the *improvement analysis* phase by performing genetic optimisation on the life cycle defined as a chromosome

5.1 The Scenario Analysis

Figure 5-1 illustrates the scenario analysis.

Figure 5-1
EAB Declaration of Task



On Life Cycle Assessment

There are several different ways to divide LCA into phases. The one used here has the phases **goal definition, inventory, classification, valuation, improvement analysis**.

Inventory is the phase where quantitative amounts of environmental loads, e.g.

- raw material use
- fresh water use
- energy use
- emissions to air
- emissions to water
- solid waste

are determined for the entity (process, product, organisation etc.) being assessed.

In *classification,* the inventory list is aggregated and different groups formed in order to structure the results according to environmental impact. Two common structurations are the *medium-oriented* and the *effect-oriented* approach. The former classifies emissions according to the receiving media (air, water, land), the latter according to impact groups (e.g. depletion, pollution, disturbance).

Valuation is the phase where classified effects one way or another are processed so that a comparison is possible. Different valuation schemes exist, but no standards so far.

Improvement analysis is where the life cycle of the studied entity is modified so that its impact on the environment is reduced - i.e. an environmental adaptive benchmarking task is performed.

On Sustainable Production, Eco-Design and the Improvement Analysis Phase of Life Cycle Assessment

The activity of using environmental criteria in improving existing entities or designing new ones is sometimes called Eco-Design. The improvement analysis phase of an LCA is an example of an activity related to Eco-Design while still distinct from it. Up to now, LCA development has been fairly linear, stage by stage, leaving the last phases with the least attention. The problems with Eco-Design and with LCA are many:

- there can be no improvement without comparison, and the valuation phase is poorly developed
- the amount of possible solutions for a normal LCA is very large, and an interactive form of improvement analysis is needed
- domain knowledge of the whole chain is needed: when a process consists of e.g. transports across oceans, mining, chemical production, a complex production process, and a complex end use solution, very many reasonable boundaries limiting the analysis have to be drawn. There is also the possibility of solutions at different points of the chain that preclude each other.

It is important to view the phase as improvement (adaptation) rather than optimisation aimed at a single optimal product.

It seems that a great hindrance to successful improvement analysis might be the lack of a suitable basic viewpoint to give a framework of reference for the operation, and tools that use the viewpoint. It is here that the Environmental Adaptive Benchmarking perspective is offered.

On Life Cycle Assessment as an Environmental Adaptive Benchmarking Task

As can be seen, LCA by itself has a very broad perspective, in that it considers the effects and impacts of the entity during its entire lifetime. That is not enough for adaptation, however. To evolve new solutions, an evolutionary viewpoint is needed. Combining the "cradle to grave" -principle with the adaptation paradigm, we have an environmental adaptive benchmarking task.

In the thesis of Vasara (1999), the GLCA concept can be encapsulated as combining genetic optimisation and visualisation using SOM-Chernoff maps and forced anchorpoints.

5.2 Features of LCA in the Example Case

The LCA, performed using the program KCL-ECO. As the aim is demonstration, details are not gone into here.

Improvement Plan: The Environmental Adaptive Benchmarking task called genetic LCA (GLCA) is the improvement plan.

Recognise: Using impacts on a national level, evaluate the fitness of a set of scenarios for training material. This fitness is expressed on a real-valued scale 0..100, with 50.0 expressing that the examined pattern matches the ideal with a probability of 50 percent. The fitness is here implemented using a backpropagation neural network trained with one expert's evaluations. Chernoff faces are used as recognition icons.

Position Use reference sets of four anchor points to position produced LCA scenarios. SOMs (self-organising maps) with Chernoff faces are used as position maps.

Adapt Use genetic optimisation with a chromosome representation of the life cycle for adaptation. Adaptation/activation diagrams, Chernoff face evolution charts and position maps are used to show the progress of the adaptation.

Measure of Fitness

As stated above, a dimensionless appraisal from 0..100 giving the nearness of a pattern to a hypothetical ideal is used as the fitness measure *entropy*. The pattern recognition capability of backpropagation neural networks is used. Visualisation is done through Chernoff faces.

Implementation

There are three sets of variables used in this GLCA:

- the primary set which contains all variables used
- the positioning set which is the selection used in the SOM mappings and statistical clusterings
- the fitness set which is the selection used by the expert in the fitness evaluation

Why these three sets? It is simpler both for the SOM process and the subsequent explanations to avoid a surfeit of dimensionality (though the SOM process certainly is capable of assimilating a far greater number of dimensions). Especially the expert in the fitness evaluation will find it easier to have a restricted number of variables to consider simultaneously, in particular as the selection is one made for this case, not e.g. a standard set of control variables the expert has lived with for a number of years.

The variables can be divided into *input* (resources) and *output* (discharges), with subdivisions energy and chemicals for the former and receiving media for the latter. The 12 variables in the *positioning set* are divided approximately equally between the groups, except for the total absence of chemicals. This judgment call is based on the fact that none of the chemicals used is particularly toxic. The fitness set is also distributed about equally. There is no one single correct set of variables; this is one choice, done for the purposes of this example case.

Training Set

24 scenarios selected for the case study were run. The six-variable fitness set presented above was given to an expert who was asked to give a rating 0..100 (or 0..1) for each scenario. A network was trained with the results of the first training set. The results were shown to the expert after which he made some modifications and a final network training was done. The network training was done using the Windows PC-program Neuroshell 2.

This method is thus exactly the reverse of weighting methods where the weights are either given directly or produced by e.g. a series of pair wise comparisons between two variables. *Here, the principle is: the big picture matters; a pattern must be evaluated as a dynamic whole.* For Chernoff faces, the order of features in e.g. the SYSTAT Statistical Program Windows PC implementation is

1. Curvature of mouth (smile=large value)

2. Angle of brow (\/=large value, /\=bad)

3. Width of nose (wide=large value)

4. Length of nose (long=large value)

5. Length of mouth (wide=large value)

6. Height of centre of mouth (up=large value)

7. 20. (Other features)

In translating the variable values to facial features, the values were first standardised and transformed so that 1 indicated the best value and 0 the worst (with the criteria chosen, there is no difficulty in determining "good" and "bad"). Thus, a broad smile, a long, wide nose and brows in V - position indicate a superb pattern. Figure 5-2 is a MUGSHOT chart where the features were mapped according to the contribution in the final network, i.e.

1. Curvature of mouth = COD (smile=low discharges)

2. Angle of brow = CO_2 balance (\/=favourable result)

3. Width of nose = coal (wide=low usage)

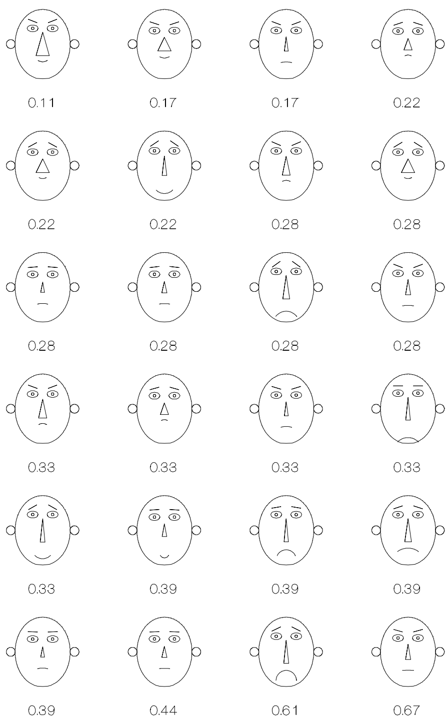
4. Length of nose = solid waste (long=low amount)

5. Length of mouth = CH_4 (wide=low emissions)

6. Height of centre of mouth = Electricity consumption (up=low value)

The figure below the faces are the evaluations given by the expert on a scale of 0..1. In this training set, no explicit ideals were given by the expert. The anchor points in the next section, what could be called utopian-dystopian pairs (i.e. specifying the ideal and the nightmare), were defined by him in the next phase.

Figure 5-2
MUGSHOT Chart



Producing the Main Map:

Now, the scenarios are mapped to a 7*7 SOM using the 12-criterion positioning set and Chernoff faces as feature indicators. The feature list for the Chernoffs is given in the previous section. The scenarios are labelled in the figures according to the following scheme:

- first digit: 1=landfill, 2=recycling, 3=incineration as the dominant disposal option
- second digit: 1=current newsprint and deinking technology, 2=estimated corresponding technology for the year 2000
- third digit: 1=coal, 2=nuclear energy as national grid dominant
- fourth digit: 1=efficient mode, 2=inefficient mode

Thus "3111" is a scenario with incineration dominating in disposal, current newsprint and deinking technology, coal - based power and efficient transport. The SOM is trained using SOM_PAK 1.2 from the Information Technology Laboratory at the Helsinki University of Technology.

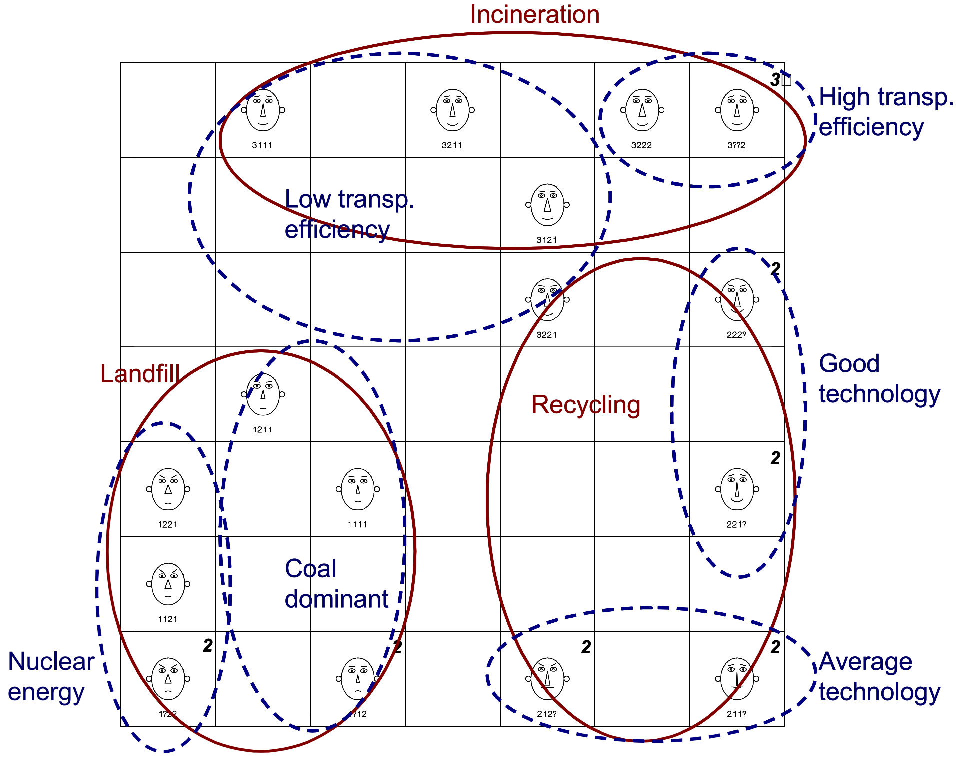
Analysis

In the main division SOM (Figure 5-3), recycling, incineration and landfill can be separated into three distinct niches. The landfill niche is characterised by fairly uniform expressions, as is the incineration niche. The recycling niche, however, is on the basis of the facial expressions and positions divided into two groups: the current technology duo and the hi-tech-duo. The recycling option "222?" (hi-tech, nuclear energy) could fit into the incineration group. *Note that the SOM has not been further analysed to distinguish distances between cells, e.g using u-matrices. This weakness should be kept in mind when considering the interpretations. However, this acknowledged weakness does not distract from the point of this case, which does not purport to analyse the situation but instead shows the method.*

From the main map, some niches can be extracted on the basis of certain negative features (Figure 5-3). Thus, the lo-tech recycling options are conspicuous by high eutrophication impacts. Also, one of them has high chemical input and the other high acidification effects. In the landfill group, the coal group has high global warming impact and large landfill space usage. The hi-tech-coal-option for recycling is characterised by high fossil fuel consumption. Finally, the three incineration options in the upper right corner are characterised by large amounts of hazardous waste.

Finally, the whole map is structured anew. Now, the landfill-coal group is characterised by low emissions and the landfill-nuclear-energy group by high amounts of solid waste. The lo-tech recycling duo is notable for high discharges and chemical inputs. The hi-tech-coal recycling scenario has high emissions, whereas the hi-tech-nuclear-energy recycling option has low discharges. For incineration, there is a low-energy and a high-fuel group.

Figure 5-3
Om the Main Division SOM



Sensitivity

In this case, two examples of types of sensitivity analyses for forest sector LCAs (and GLCAs) are

- analysing the propagation of changes along the chain
- analysing the impact of different levels of e.g. technology and furnish on results

Here, we are looking at the propagation of changes resulting from a perturbation at one point in the chain. The association is to the life cycle as the calm surface of a lake. As if small stones were thrown, small ripples appear on the surface and disturb the equilibrium. Two types of questions are examined:

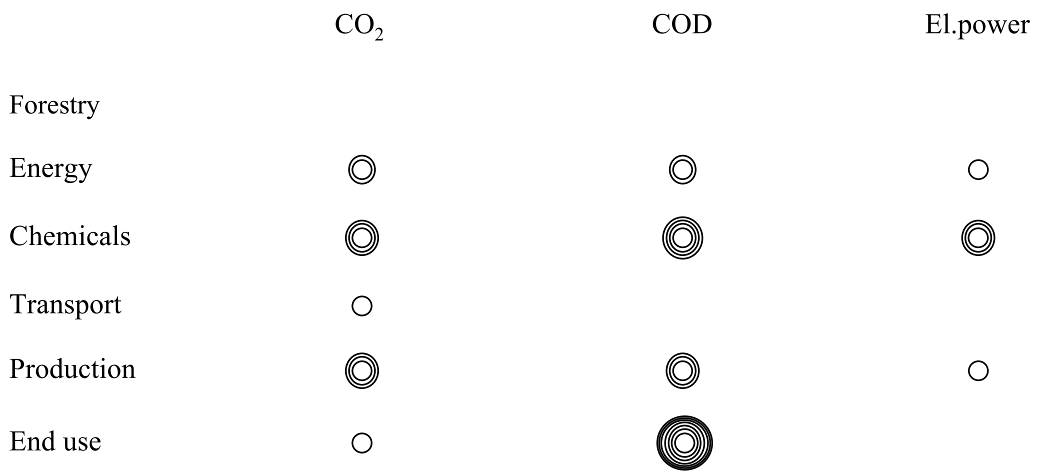
- Locus: what happens at different points of the life cycle if we make one perturbation?
- Global: what are the overall changes when we make a series of perturbations of one variable?

The *locus* question to be analysed is: if we *change the recycling ratio* from 60 to 50 percent, what happens to the *criteria* carbon dioxide, COD and electricity at the *points* forestry, energy production, chemicals, transport, production and end use *in the chain*?

The *global* analysis is formulated: if we *change the recycling ratio stepwise* from 60 to 50, 40 and 30 percent, what are the *global effects on the criteria* NO_x, SO_2, CO_2, CH_4, BOD, COD, leachate, fuel, electricity and coal?

In Figure 5-4 the relative changes resulting from a change of recycling ratio from 60 to 50 percent for one particular scenario are shown in a *ripple*-diagram. The variables examined are carbon dioxide, COD and power use at different loci in the chain (forestry, energy, chemicals, transport, production and end use).

Figure 5-4
Ripple-diagram: Lowering Recycling Ratio from 60 to 50 percent



As has been said before, the idea is to show perturbations as ripples on the surface of a lake. A scaling is performed, and one ring corresponds to a change of 5 percent (the direction is irrelevant here, but could be shown e.g. by colour-coding).

In Figure 5-5, the relative changes for a group of 10 variables (part of the positioning set) over the entire life cycle, resulting from a change of recycling ratio from 60 to 50, 40 and 30 percent for one particular scenario are shown. Here, most of the changes are jumps upward, the greatest being a increase of over 80 percent for COD in the 30 percent recycling option[6]. The greatest reduction is almost 40 percent for coal in the 30 percent option. The comparisons are always to the 60 percent recycling base scenario.

The same facts can be expressed in a *ripple*-diagram as in Figure 5-5.

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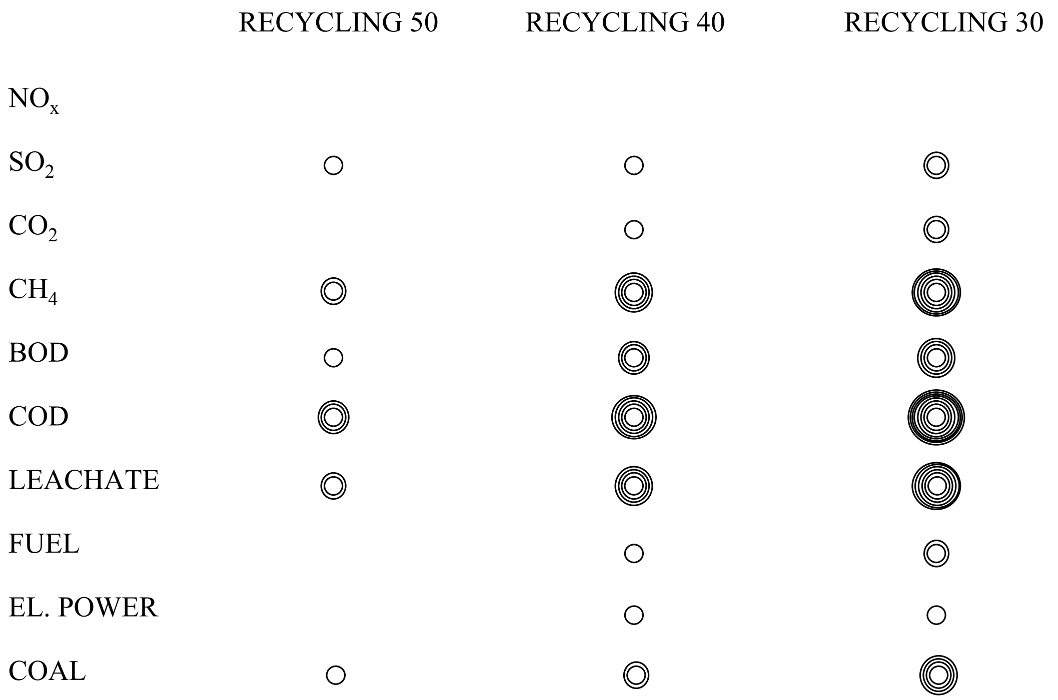
[6] Note: here we have sums over the entire chain, not points in the chain as in the previous view

Figure 5-5
Ripple-diagram: Lowering Recycling Ratio from 60 to 50, 40 and 30 percent



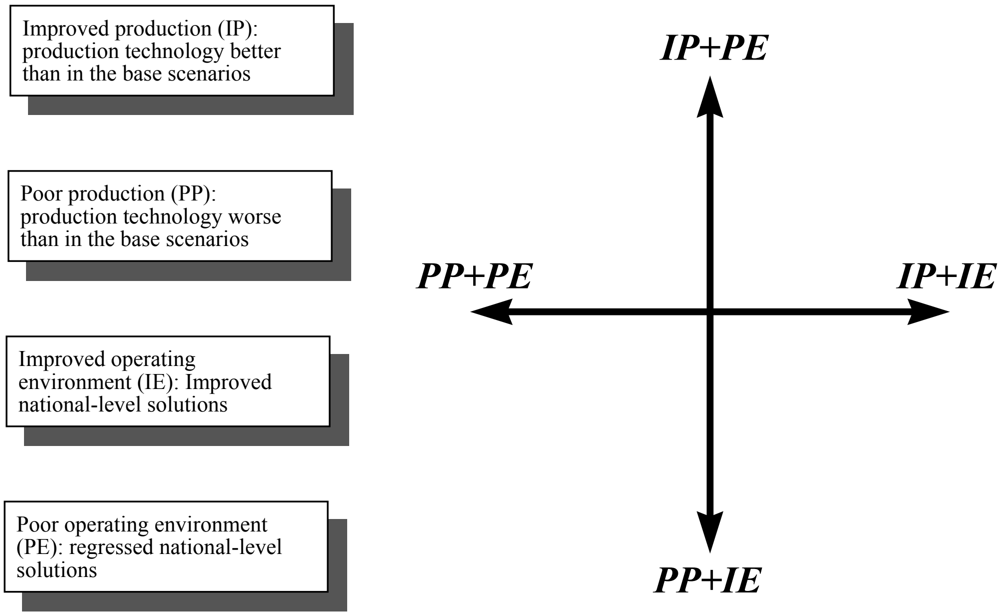
In the scaling here, one ring corresponds to a change of 10 percent (the direction is again irrelevant).

Reference Set: Anchor Points

After the initial training of the fitness evaluator network, the expert was asked to define four *anchor point* scenarios to function as a reference grid in positioning. The anchor points were defined as outlined in Figure 5-6.

Improved production (IP) denotes a production technology better than any in the base scenarios, with minimum emissions, effluents and energy consumption. *Poor production (PP)* is characterised by energy intensive technology, minimum discharge control and no sludge incineration. *Improved operating environment (IE)* shows *in this case* electric power mainly from nuclear and hydro-electric sources; heat mainly from gas; efficient transportation and collection. *Poor operating environment (PE)*, finally, is a coal-based, landfill-dominated option of inefficient transport. These anchor points are the reference set that divides the map into four sectors as in Figure 5-6.

Figure 5-6
Anchor Points for CLCA Case



Scenarios with the anchor point definitions were run and are used in the ADAPT section. The evaluations for the anchor points using the fitness network (best = 1.00, worst = 0.00) are:

IP+IE: 0.691

IP+PE: 0.257

PP+IE: 0.157

PP+PE: 0.148

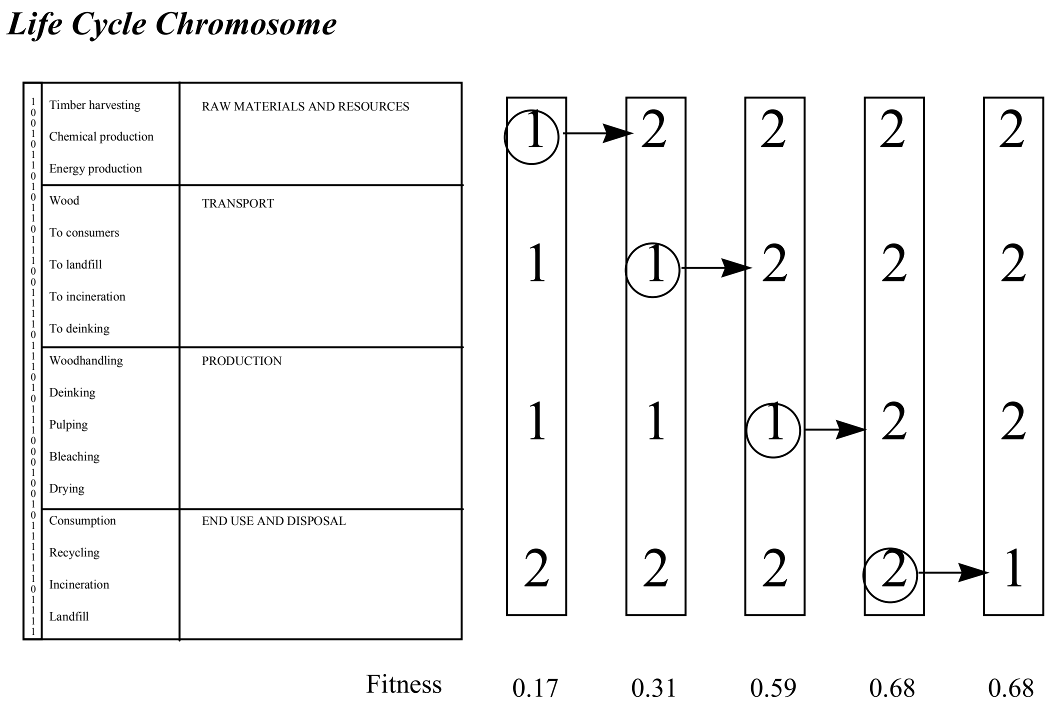
Adapt

As mentioned before, there is no Genetic LCA software on the market. It is possible to use genetic shells and link them to a life cycle solver, but the tool used here, KCL-ECO, does not permit such solution. Therefore, the outlined genetic LCA implementation of the EAB task "improvement analysis of a life cycle" is demonstrated by hand. The adaptation procedure below is completely realistic, but very simple, with a short chromosome and only five steps. It should, however, illustrate the method adequately.

Steps

From among the 24 base scenarios, 5 were chosen. This quintet presents a series of improvements in fitness through changes at one single place in the chromosome. Figure 5-7 shows the steps in the "simulated adaptation".

Figure 5-7
Steps in Adaptation



Thus e.g. the first step involves changing from landfill domination to a recycling option and improving fitness from 0.17 to 0.31.

Faces, Activations, Wanderings

To illustrate the adaptation process, changes in Chernoff faces, adaptation diagrams and paths in position maps are used.

In it, IP+IE and IP+PE sit at their appointed places, whereas the two other anchors are slightly askew. However, the trend is clear: the adaptation starts between the poorest anchor point and the point with improved production, progresses to the centre of the field and ends up in the upper right corner. The facial similarities between the "ideal" point IP+IE (improved production and improved operating environment) and the end point of the adaptation path are obvious (the same interpretation rules still apply).

Conclusion

In analysis of the environmental impacts of *products*, Life Cycle Assessments are the most commonly used environmental tool today. An LCA itself is a good illustration of the complexity of environmental issues: the interconnections between elements in an LCA flowchart are but a shadow of the complexity of the real world, but effective as a demonstration.

For the LCA performed, we could repeat results from the interpretation process in the chapter. But: these conclusions only apply to this particular LCA, which does not purport to portray any actual situation. Thus, the issues of primary fibre injections and closed industrial systems (which attempt to fulfill recycling in near isolation) and open industrial systems (which achieve results by import/export) hover near the surface, but never break out in full.

The more important conclusion is that linked to the question of GLCA as an environmental adaptive benchmarking task. Given the relative ease with which the improvement analysis phase of LCA fit into the framework, it is probably reasonable to assume that the method described could be used e.g. in an actual software implementation and thus be quite far removed from mere theory. The subjective valuation theme is embodied in a neural network fitness scheme based on an expert's opinions.

6 BENCHMARKING CASE 3: THREE COMPANIES (BRE)

In this benchmarking case, benchmarking sets of three companies are presented.

Company 1

Outline (characteristics)
Timber frame manufacturers fabricating timber frame walls, floors and roofs.
Using solid timber, wood based panel products, LVL and I-joists supplied from various sources. Truss rafters for roofs manufactured on site.
The panels are open, and are completed on site with insulation and plasterboard.
Large company, 2 sites in the UK (geographically close)

Timber inputs:
Timber from 6 different suppliers
Panel products chipboard and OSB from 4 sources
LVL from one source
I-joists from 5 sources

Problem
No system in place to run real figures of input and outputs allowing for cross check
High wastage rate due to inaccurate data from sampling

Waste management
Waste is removed from site by 2 contractors, for recycling and landfill
Waste was not been clearly monitored by the contractors in terms of mass or content
Waste rate

- Landfill about 80% by weight
- Recycling about 20% by weight

Consequences
LCA study produced very poor results. The identification of manufacturing ‘hot spots’ and selecting practicable solutions.

Improvement
Waste management recording by the company & waste contractors improves (mapping & identifying solutions)

- Landfill about 50% by weight & recycling about 50% by weight, which translated to lower environmental impacts caused by waste
- This also contributed to financial saving on landfill fees
- The company has invested in a strengthening of input and output system in-house system with an informed starting position

Company 2

Outline (characteristics)
Timber frame manufacturers fabricating timber frame walls, floors and roofs.
Using solid timber, wood based panel products, LVL and I-joists supplied from various sources. Truss rafters for roofs manufactured on site. Production is computerised drawings and cutting plans.
The panels are open, and are completed on site.
Large company, geographical distribution all throughout the UK (only one site was under review)

Timber inputs:
Timber from 3 suppliers
Panel products (plywood and OSB) from 2 suppliers
LVL from 1 supplier
I-joists from 1 supplier
All suppliers FSC or PEFC certified

Waste
All recycled, re-used, or sold (for further processing, e.g. kindling)

Problem
No CoC system in place, no procedure/space for segregation of certified and non-certified material.
In-house system for inputs and outputs figures that was not designed to include CoC requirements.

Consequences
Broken chain precluded any product claims, which resulted in a loss of business opportunities (particularly with the public construction sector)

Improvement
Supply chain (sustainable supply) supported the company's work towards CoC
In-house system flaws have been identified (misinterpretation of inputs and outputs).

Company 3

Outline (characteristics)
Timber frame manufacturers fabricating timber frame walls, floors and roofs.
Using solid timber, wood based panel products, LVL and I-joists supplied from various sources.

The panels are open, and are completed on site.
Medium company (one site)

Energy
1 - Wood dust extraction fans
With 50Kw use of energy translates to £4.50/hour to run. This cost equates to around £11,000/year, plus further costs incurred during winter to heat the air which is then extracted.

2 - Compressed air
This function represents typically 20-30% of manufacturing site electricity usage (problems with air leaks)

3 - Lights in offices, lavatories, workshops (inefficient equipment)

4 - Space heating – importing energy

Problem
No measurement of any utilise use
Inefficient equipment - waste of energy (air leaks, non-energy efficient bulbs, etc)

Consequences
Energy use and energy expenditure high and rising

Improvement
Fitted invertors for all wood dust extraction and therefore cut costs of running these.
A comprehensive installed a system fro reporting /weekly repair PLUS correct pressure)
Sensors for natural light levels & movement
Energy efficiency bulbs
Secured energy-efficiency loans (interest free) £5,000 - £100,000 to install wood combustion plants (saved on waste disposal prices & rising energy prices)

Could not consider cheap electricity rate (time rate) as energy provider did not have this option.

Saving approximately 18% of energy use

7 CONCLUSIONS FROM THEORY AND CASES

The nucleus of different environmental benchmarking methods is the desire to measure the environmental performance of an entity, be it a project, a product, a mill, an organisation, an industry, an industry scenario, a process, an ecosystem or something in a very wide sense comparable. What is sought is generic excellence (Spendolini 1992) whatever the performer or the field. A further common characteristic is the need to *measure, compare and improve* the environmental performance discussed.

However, in trying to gain an insight into the tapestry of environmental assessments, a unified *framework* is of the essence. Adaptive benchmarking concept, which is not bound to only environmental issues, is an example of such a flexible framework.

The contents of this work should be kept in mind in the compilation of response functions e.g. in work packages 4.2 and 4.3. In addition, the range of possibilities and need of tailor-making in environmental comparisons and benchmarking should be kept in mind in M1, the development and interpretation of ToSIA. In some parts, this work reflects also Delivery 4.2.2 “Report on review of existing tools”.

The big picture matters; a pattern must be evaluated as a dynamic whole.

ABBREVIATIONS

BI	Benchmarking indicators
BOD	Biochemical oxygen demand (5 or 7 days)
CH_4	Methane (gas)
CO_2	Carbon dioxide (gas)
COD	Chemical oxygen demand
EAB	Environmental adaptive benchmarking
EAB LCA	Environmental adaptive benchmarking LCA
EIA	Environmental impact assessment
FWC	Forestry Wood Chain
GLCA	Genetic LCA
LCA	Life cycle assessment
NO_x	Notation for a combination of nitrogen oxides formed in combustion units; usually measured as NO_2 (nitrogen dioxide)
SA	Sustainability analysis
SO_2	Sulphur dioxide (gas)
SOM	Self-organising map
SOM-Chernoff map	A SOM map made using cartoon-like depiction of a human face to illustrate multidimensional vectors

REFERENCES

Bendell, Tony; Boulter, Louise; Kelly, John (1993): Benchmarking for Competitive Advantage. Pitman Publishing, London, 266 pages

Camp, Robert C (1989): Benchmarking: the Search for Industry Best Practices that Lead to Superior Performance. ASQC Quality Press, Milwaukee, Wisconsin. 299 pages

Coplien, James O (1994): Examining the Software Development Process. Dr. Dobb's Journal 19, October 11, 1994, 88-97

Davis, Lawrence (1991): Handbook of Genetic Algorithms. Van Nostrand Reinhold, New York

Fava, James; Consoli, Frank; Denison, Richard: et al. (Eds.) (1993): A Conceptual Framework for Life Cycle Impact Assessment. Society of Environmental Toxicology and Chemistry, Pensacola, Florida. 160 pages

Finnveden, Göran; Lindfors, Lars-Gunnar (1992): LCA – Methodologies for Classification. Manuscript presented at the Life Cycle Analysis Symposium in Potsdam, 25-26 June 1992, organised by SETAC-Europe. IVL Report B 1063. Institutet för Vatten- och Luftvårdsforskning, Stockholm. 19 pages

Fitz-enz, Jac (1994): Benchmarking Staff Performance: How Staff Departments Can Enhance Their Value to the Customer. Jossey-Bass Publishers, San Francisco, 218 pages

Hameri, Ari-Pekka; Eloranta, Eero (1994): Free Trade and Ecology – Benchmarking as a Method towards a Sustainable Future. IFIP WG5.7 Workshop on Benchmarking – Theory and Practice, Trondheim, Norway, June 16-18, 1994. 9 p (N)

Karlöf, Bengt; Östblom, Svante (1993): Benchmarking: s Signpost to Excellence in Quality and Productivity. John Wiley & Sons, Chichester, England. 197 pages

Laamanen, Kai (1993): Jatkuvan parantamisen kehittäminen. Laatuviesti 3/1993, 15-17

Lindfors, Lars-Gunnar; Hirsbak, Stig; Goldstein, Berit; et al. (Eds) (1992): Product Life Cycle Assessment – Principles and Methodology. Nord 1992:9. Nordic Council of Ministers, Copenhagen. 288 pages

Simons Consulting Group (1994): Forestry Sector Benchmarking Initiative: A Case Study in Environmental Regulations. Final Report. W549A, Nov. 1994. Department of Natural Resources (Canadian Forest Service) and Industry Canada

Spendolini, Michael J (1992). The benchmarking book. AMACOM, New York, NY. 207 pages

Valve, Jorma; Kolehmainen, Ari (1994): Kuntien johtamiseen uutta välineistöä – oma tehottomuus paljastuu vertaillen. Kuntalehti 16/1994, 46-47

Vasara, Petri (1999): Environmental Adaptive Benchmarking: A Framework for Environmental Assessment. Acta Polytechnica Scandinavica, Chemical Technology Series No. 268, Espoo, Finland)

Watson, Gregory H (1993): Strategic Benchmarking: How to Rate Your Company's Performance against the World's Best. John Wiley & Sons, New York, 269 pages