Eco-Serve
Task 2: Environmental Baseline and Indicators

Prepared by:
Danish Technological Institute,
Kirsten Pommer
and
Intron B.V.
Agnes Schuurmans
Joep Meijer

November 2004

Title: Task 2: Environmental Baseline and Indicators

Author: Danish Technological Institute,
Kirsten Pommer
and
Intron B.V.
Agnes Schuurmans and Joep Meijer

Table of content

1. Introduction

1.1 The Eco-Serve Network

Eco-Serve is a network, contracted by the European Commission, with 15 European industries and research institutes. It focuses on the environmental impact of the construction industry exemplified and focused on materials production.

1.2 Objectives

The objectives of Eco-Serve are:

- Reduce the environmental impact of the construction industry
- Improve the working environment
- Contribute to growth and wealth by increasing productivity / competitiveness / quality.

The following targets are suggested:

- 30% reduction in CO_2 emission of the present level (measured on the relevant segment of the industry)
- 20% reduction in hydrocarbon consumption (through reduced need for fuel, bitumen and transportation energy)
- 20% reduction in need for transportation of aggregates for construction
- 20% reduction in construction cost for comparable qualities

Eco-Serve has four industrial clusters at its core, all with a material focus:
Cluster 1: use of wastes as secondary fuels and raw materials for cement production
Cluster 2: production and application of blended cements
Cluster 3: concrete and aggregate production
Cluster 4: pavements

The management of the project is fulfilled by a Steering Committee and a 'task 2' group that supports the clusters in the definition of sustainability indicators, the definition of environmental baseline and BAT and co-ordinates between the clusters.

1.3 Goal for Task 2

The objectives for Task 2 can be summarised as follows:

- ♦ To create a European baseline for the best available technology and the environmental impacts as regards the production and use of cement, aggregate, concrete and pavement in a life cycle perspective.
- ♦ To establish and validate environmental indicators for innovative cement, aggregate, concrete products, and pavement.
- ♦ To establish an interactive platform for mapping stakeholders through the E-core network facilities.

1.3.1 The life cycle perspective as a basis

The Eco-Serve objectives have been chosen mainly from studies focusing on cleaner materials production. Nevertheless, in order to reduce the environmental impact, the full life-cycle perspective should get rightful attention throughout the indicator selection process.

So-called 'life cycle thinking' reflects the acceptance that key societal actors cannot strictly limit their responsibilities to those stages of the life cycle of a product, process or activity in which they are directly involved. It expands the scope of their responsibility to include environmental implications along the entire life cycle of the product, processor activity.

The life cycle in the construction industry looks in principles as shown in Figure 1.1.

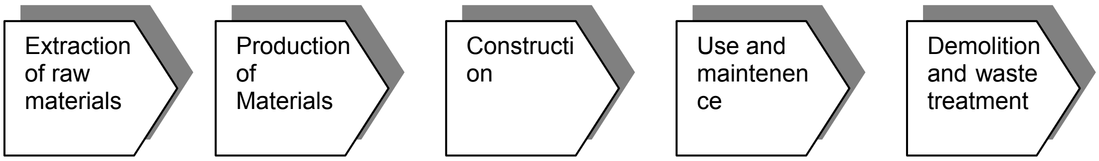


Figure 1.1 General life cycle for constructions.

The life cycle perspective in Eco-Serve should:

- maintain benchmarking and life-cycle perspectives by way of the environmental baseline
- identify process–product links across life-cycle stages
- allow for life-cycle adaptation of best-available-techniques (BATs)
- ensure overall feedback to materials design.

1.3.2 Cluster activities

The cluster activities consist of:

1. data collation of the current status and existing technologies,
2. mapping the inventory results, and
3. providing guidelines about environmentally friendly options.

The mapping includes the definition of an environmental baseline and the currently best available technologies (BATs).

The drawing of the environmental baseline corresponds to entering the collected data in an industrial benchmarking exercise. Indicators are defined to be able to do the mapping. This is illustrated by Figure 1.2.

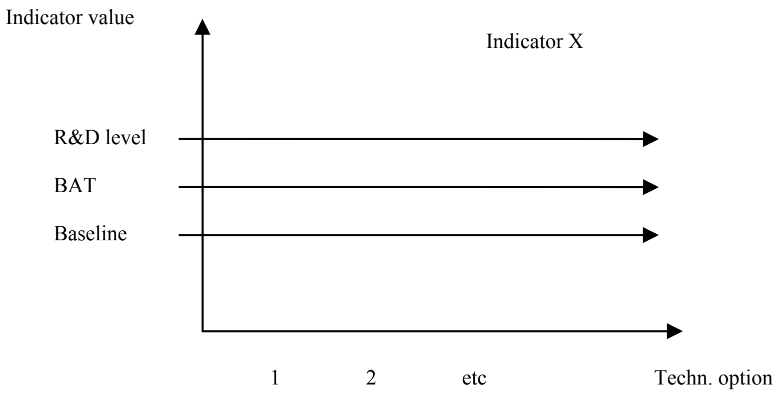


Figure 1.2 The mapping exercise

1.3.3 The tree elements in task 2

The above stated objectives for Task 2 can be achieved by carrying out the following 3 sub-tasks.

Task 2.1 Establishing BAT
Task 2 will develop the tool and the guideline for collecting data from Cluster 1-4 and will systematise and evaluate the data to BAT's for all the industries represented in ECO-SERVE.

Task 2.2 Environmental baseline
Task 2 will create a baseline for the environmental impact from the activities in the clusters in a life cycle perspective. This baseline shall not consist of exact LCA's, but give an overview an d point out the most important issues. The baseline will be based on existing relevant studies as well as inputs from the clusters.

Task 2.3 Environmental indicators and tool
Task 2 will establish environmental indicators and develop guidelines / tools showing how to use these indicators in the clusters.

The relationship between Task 2 and the other activities in ECO-SERVE is illustrated in Figure 1.3.

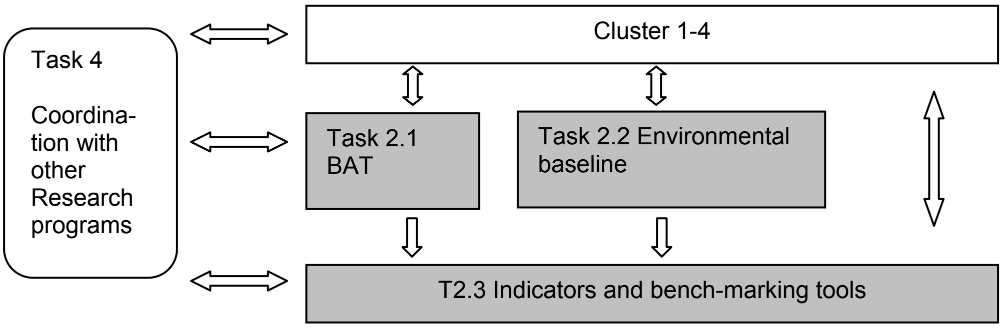


Figure 1.3 Sub-Tasks in Task 2 and other activities in ECO-SERVE

1.3.4 Limitations of Eco-Serve

Eco-Serve limited itself as follows:

- The life cycle perspective is limited to the material-related part of the life cycle. The use stage of a building (although important for the environmental impact) is excluded in the Eco-Serve activities.
- The activities are limited to concrete. Other materials, like reinforcement steel, are not studied.
- Results from existing LCAs on concrete are used as a basis. New LCAs are not carried out.

1.4 About this report

This report provides the backgrounds of the approach in the selection of indicators and presents the definition of the selected indicators.

It is a justification of the selected indicators and shows the relationship between the clusters in the whole life cycle perspective of concrete.

1.4.1 Target group and role

Target groups of this report are:

- the project partners / the clusters;
- the broader community that is interested in the environmental impact of concrete.

Shorter versions of elements of this report that are of special interest for the industry will prepared in order to communicate the main results to a broader target group.

1.4.2 Structure

The structure of the report is as follows:

Selected background materials and important principles used in Task 2 are presented in chapter 2.

Methods and principles for indicators and other elements used in the framework of Task 2 is presented in chapter 3.

Chapter 4 covers the work done related to cluster 1, Alternative fuels and consists of indicators, the baseline study, tools for benchmarking as well as other findings related to the cluster.

Cluster 2 is focused on to major issues, - aggregates and concrete. These two are presented in separate chapters, chapter 5 and 6. These chapters cover the work done and include the same issues as in chapter 4.

In chapter 7 is presented the work of cluster 3, Blended cement and in chapter 8 is the work of cluster 4, pavement presented.

In chapter 9 general indicators for the whole life cycle is presented.

2. Background

2.1 Sustainability and life cycle thinking

2.1.1 What is sustainability?

The Brundtland Commission Report, Our Common Future (*World Commission, 1987*) , defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Principle 1 of the Rio Declaration (1992) also established that: "Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature".

Sustainable development has three principal dimensions (*Guidance for Preparing, 1987*):

- ♦ Social equity
  An improvement of economic welfare and quality of life in the developing world
- ♦ Protection of the environment
  A healthy environment with resources used and conserved wisely – world
- ♦ Economic growth
  A socially and environmentally innovative, resource efficient economy that delivers quality of life in the developed world

These dimensions are also referred to as the 'three P's': <u>People</u>, <u>Planet</u>, <u>and Profit.</u>

2.1.2 Life cycle thinking and clean technology

Clean Technology is a concept used in the manufacturing and processing industries for avoiding pollution and waste at source. One definition of Clean Technology is that it is the means of providing a human benefit which, overall, uses less resources and causes less environmental damage than alternative means with which it is economically competitive, thus providing a basis for sustainable development.

An approach based on life cycle thinking is essential to exclude technologies that improve one manufacturing process at the expense of increased environmental impacts in upstream or downstream processes. Thus the life cycle concept can - and should - have a central role in defining Clean Technologies, although the object of analysis in the latter concept is industrial processes and technologies.

LCA would be one of the essential options to precede a life-cycle thinking approach throughout the organisations. It emphasises on a process which evaluates the environmental burdens associated with a product system, or activity by identifying and quantitatively describing the energy and materials used, and wastes released to the environment, and to assess the impacts of those energy and material uses and releases to the environment.

LCA addresses environmental impacts of the system under study in the areas of ecological systems, human health and resource depletion. It does not address economic or social effects, which will be sufficient to appraise the environmental aspects of sustainability.

Social and economic aspects can be covered by a similar life cycle approach, using other impacts as the basis for measurement. Life Cycle Costing is an already accepted tool for the economic aspects. Social issues in a life cycle perspective is still in it's infancy.

2.1.3 Initiatives on sustainable concrete, cement and minerals

2.1.3.1 Centre for Green Concrete

In Denmark a centre for Resource Saving Concrete Structures (*Glavind, M., and Munch-Petersen, C., 2002*) is formed with the aim of reducing the environmental impact from concrete. To enable this, new technology is developed. The technology considers all stages of a concrete construction's life cycle, i.e. structural design, specification, manufacturing, maintenance, and it includes all aspects of performance.

The four ways to produce green concrete are the following :

1. To increase the use of conventional residual products, e.g. fly ash in large quantities;
2. To use residual products from the concrete industry, i.e. stone dust (from crushing of aggregate) and concrete slurry (from washing of mixers and other equipment);
3. To use residual products from other industries not traditionally used in concrete, e.g. fly ash from bio fuels and sewage sludge incineration ash (from sewage treatment plants);
4. To use new types of cement with reduced environmental impact, e.g. mineralised cement, limestone addition, and waste-derived fuels).

The Centre defines 'green' concrete as concrete, which satisfies one or more of the environmental goals, which are aimed for:

- concrete with minimal clinker content
- concrete with green types of cement and binders
- concrete with inorganic residual products
- operation and maintenance technology for green concrete structures
- green structural solutions and structural solutions for green concrete.

This green concrete should reach the following goals:

- CO_2 emission caused by concrete production must be reduced by at least 30%.
- The concrete must consist of at least 20% residual products, used at aggregates.
- The concrete industry's own residual products must be used in concrete production.

- New types of residual products, previously landfilled or disposed of in other ways, must be used in concrete production.
- CO_2-neutral, waste-derived fuels must replace at least 10% of the fossil fuels in cement production.

Moreover, a green type of concrete has to meet all of the environmental intentions listed below:
- avoid the use of materials which contain substances on the Danish Environmental Protection Agency's list of unwanted materials;
- do not reduce the recycling ability of green concrete compared to conventional concrete (today, 95% of the concrete is reused);
- do not increase the content of hazardous substances in discharge water from concrete production.

Further information regarding this project can bee retrieved from the homepage www.greenconcrete.dk.

2.1.3.2 Product development in the concrete industry

The Danish EPA included in its programme on Cleaner Products a special initiative for supporting development of sustainable products. Among other types of products focus was on concrete.

The project started in 2003 and included as the first step construction of an actionplan, based on inputs from all parties in the life cycle of a concrete product. This means that all major parties with interests in the concrete industry were involved in deciding in which directions the product development was most efficient regarding sustainability and general competition.

The subproject which were selected are assessments regarding:
- Leaching of hydrocarbons and proposals for threshold limits for waste materials.
- Use of crushed concrete in order to save aggregates
- Concrete and indoor climate, positive and negative effects.
- A 50 percent potential energy saving regarding dehydration of concrete
- Leaching of heavy metals from fly ash and other recyclable waste products that can be used in concrete.
- Reduction of energy for drying new constructions and at same time reduce the level of in-door climate problems as well as reduce damages by damp.

The results from these subprojects are expected to be available and implemented in the industry in 2005-2006.

2.1.3.3 Concrete for the environment – a Nordic network

The Nordic network Concrete for the Environment aims at a common understanding of sustainable cement, aggregate, concrete and pavement. The following guidelines are developed for 'green' concrete structures:

- designed, built, operated or re-used in a resource-efficient manner
- utilising the inherently environmentally beneficial properties of concrete
- tailor-made for use
- total environmental impact during the entire life cycle reduced to a minimum.

Five criteria are formulated:
- use aggregate that is extracted in an environmentally friendly manner
- use cement manufactured using modern production technology, recycled raw materials and alternative energy sources
- be produced at concrete plants where environmental impact is minimised
- have an optimal clinker content according to the intended strength and durability
- not introduce environmental problems such as leaching of heavy metals etc..

Examples are:
- use recycled products such as silica fume, fly ash, slag etc
- use the good durability of concrete to increase the service life
- use the strength to minimise the total concrete volume needed
- use the thermal capacity to reduce the energy consumption.

Further information can be obtained at www.nordicinnovation.net by searching for the project name.

2.1.3.4 Towards more sustainable cement

According to the World Business Council for Sustainable Development, in order for the global cement industry to make genuine progress toward sustainable development, it must address all three dimensions of sustainability: environmental, social, and economic (*The cement sustainability initiative, 2002).*

To address these issues and to provide vision and direction for a more sustainable approach to the industry's future growth, the WBCSD worked with the industry to carry out a sector project on cement. The Cement Sustainability Initiative (CSI) was formed for this purpose. The business leaders of a group of major cement companies lead the initiative.

Its purpose is to:
- explore what sustainable development means for the cement industry
- identify and facilitate actions that companies can take as a group and individually to accelerate the move towards sustainable development
- provide a framework through which other cement companies can participate
- provide a framework for working with external stakeholders.

An agenda for action has been developed in 2002 following a three-year program of scoping, research and stakeholder consultation looking at what sustainable development means for the future of the cement industry. It sets out a program of work for the period up to 2007 focusing on the following six areas which are identified as important and prioritised to start with (environmental and social):

- climate protection (CO_2);
- fuels and raw materials (responsible use of all fuels and raw materials);
- employee health and safety;
- emissions reduction;
- local impacts;
- internal business processes (integration of sustainable development);
- an invitation to join (other cement companies);
- reporting progress.

The individual companies hope to benefit from the new business opportunities created by sustainable development.

2.2 Relevant LCA-studies

Many studies with the purpose of assess the environmental aspects of using concrete has been studied in the context of this report. In the following some of the most relevant studies are described.

This section is divided into four parts focusing on LCA-studies and other studies for concrete, studies regarding aggregates and relevant databases. At the end of the section the major findings are summarised.

Completeness in the description is not suggested. Many other LCA concrete studies are available in Europe, often in national languages.

2.2.1 LCA-studies regarding concrete

2.2.1.1 TESCOP

TESCOP (Cleaner Technology Solutions in the Life Cycle of Concrete Products) was a European BRITE-EURAM project in which LCA studies were performed to detect potential cleaner technology solutions for concrete (*Glavind et al., 2001*).

The results showed that cleaner technologies should mainly be developed in the areas of CO_2 savings, energy savings, the use of secondary materials, waste minimisation, water use, minimisation of use of dangerous substances, SO_2 and NO_x emission reduction, and other emission reduction.

2.2.1.2 LCA of cement and concrete in the Nordic countries

An LCA of Cement and Concrete was performed for the Nordic countries, initiated by the Nordic cement industry represented by Finncement AB (Finland), Cementa AB (Sweden), and Norcem A/S (Norway), which was carried out by STØ, Østfold Research Foundation (*Vold and Rønning, 1995*).

From the LCI of cement production, it could be deducted that clinker production system is the most important part of the manufacturing process in terms of environmental issues. The main use of energy is the fuel for clinker production. The mills and the exhaust fans mainly use electricity

To support the finding it is stated in ‘LCA of Cement and Concrete’ that according to the CML model the main emissions, which have big environmental impacts, are NO_x, CO_2, SO_2 and the consumption of fossil fuels. Electricity follows as the next contributor to the environmental impact of cement production.

2.2.1.3 LCA project concrete of the European Joint Project Group

A joint initiative of six European associations (BIBM, CEMBUREAU, EFCA, EISA, ERMCO and UEPG) representing the concrete industry or constituents, resulted in a project called ‘LCI/LCA of concrete’ (*Lanser, P, 2002*). The aim of this project was to provide the concrete industry with a set of credible arguments to demonstrate the sustainability of concrete and meet the expectations from both the market place and public authorities at EU and national levels. The main findings was:

- Concrete can easily be made fit for purpose. This results in an optimised amount, composition and processing of the concrete in its applications. The environmental impact consequently is optimised towards the required performance during the service life.
- As a material, concrete requires little maintenance during the service lifetime and, if properly maintained, does not have to be replaced within this service lifetime, resulting in a minimised environmental impact.
- This long service lifetime can be achieved with “concrete” ingredients (cement, reinforcing steel, aggregates, admixtures and water) only, whereas the use of protective coatings will result in additional environmental impacts and risks.
- Reinforced concrete and its constituents can be economically recycled a number of times and is 100% in line with closed-loop recycling strategies.

The study is carried out according to ISO 14040-14043 and it was developed by INTRON in the Netherlands as an external consultant to carry out the study together with the six associations. The basic data have been supplied by industry, collected by INTRON. The results are peer reviewed by IKP, from Germany, according to the ISO 14040-series.

2.2.1.4 LCA of sewer pipes

The Danish EPA funded in 1998 a project which goal was to compare the environmental profile of sewer pipes made from different materials (*Nielsen et al, 1998*). In the comparison was included pipes made of concrete, PVC (polyvinyl chloride) and PP (polypropylene).

In the study was used the Danish LCA-tool based on the EDIP-method and the functional unit was 1 meter of pipe with the same capacity and a lifetime of 100 years.

The study showed the following:

- Most of the materials spend was used in the production of materials. This was seen for concrete, PVC and PP. The difference is, that the resources used for concrete are not scarce non-renewable resources, as it is for PVC and PP.
- The most energy was spend on construction of the pipe line. This holds for all types of pipes.
- Energy spend on production of pipes is about the same for polymers and clinker.
- The contribution to the green house effect (carbon dioxide) was a little higher for the pipes on concrete compared to the other types.

The conclusion of the study showed that an efficient construction of the pipeline was very important. Also of importance was the recycling of materials after use. Regarding recycling there are more opportunities for reuse of concrete than for plastics.

2.2.2 Other studies regarding concrete

2.2.2.1 Background information on clinker production

According to the conclusion derived from the LCI/LCA, the main contributors of environmental impacts in concrete production are the cement production, specifically through clinker production. Therefore, in this section focus will be on the clinker production.

The composition of clinker is shown in Table 2.1. From this can be seen that about 2/3 of the content is calcium oxide and the other major component is silicium oxide. The rest is metal oxides and small amounts of sulphur oxide.

Table 2.1 Chemical and mineralogical composition of clinker (Chaniotakis, E.et al., 2002)

Chemical composition (%)		**Mineralogical composition (%)**	
SiO_2	21.79	C_3S	65.15
Al_2O_3	5.13	C_2S	13.32
Fe_2O_3	3.59	C_3A	7.54
CaO	66.42	C_4AF	10.92
MgO	1.71	*Moduli*	
K_2O	0.55	LSF	95.70
Na_2O	0.09	SR	2.50
SO_3	0.52	AR	1.43
others	0.20	HM	2.18

Ordinary Portland clinker of industrial origin contains limestone of high calcite content ($CaCO_3$: 95.3%).

The formation of carbon dioxide originates from the calcination of limestone and for the combustion of fuel. Both contributions are important, while each contribute to about 40-60 percent of the total amount of CO_2 released from the clinker production.

The process of calcination follows the reaction:

$$[1]\ CaCO_3 + \text{energy} \rightarrow CaO + CO_2$$

which means that in theory 0,44 kg CO_2 is formed per kg limestone ($CaCO_3$). Calcination of lime takes place at temperatures above 800 °C. The calcination in cement kilns is complete but in lime kilns 0.5–2% of the carbonates remains as there is a fear of overburning (*Bahr, B.von and Steen, B., 2003*).

Carbon dioxide is also formed in the combustion process. The amount of carbon dioxide formed depends on the amount and type of fuel used and energy content of the fuel.

For instance the main component in coal is pure carbon, which burns using oxygen following the reaction

$$[2]\ C + O_2 \rightarrow CO_2$$

If natural gas is used the reaction is:

$$[3]\ CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$$

In Table 2.2 is shown some data for selected types of fuel and how much CO_2, that is formed per unit of released energy.

Table 2.2 Formation of carbon dioxide from different types of fuel

Fuel	Mole-weight g/mole	Number of moles per kg fuel	CO_2 per kg fuel	Energy content MJ/kg [1)]	kg CO_2 per MJ
Coal	12	83.3	3,67	29.5	0.124
Diesel oil [2)]	170	5.88	3.11	42	0,074
Natural gas	16	62.5	2.75	48.5	0,067
Cellulose [3)]	162	6.17	1.63	20	0.081

[1):] Lower calorific value
[2]): Diesel oil is equivalated to $C_{12}H_{26}$
[3):] Cellulose can represent paper or wood, - assumed that is 100 % dry with for formula $(C_6H_{10}O_5)_n$

As can bee seen in Table 2.2 using natural gas will form the lowest amount of carbon dioxide per unit of energy released in the burning process. Although oil contains other hydrocarbons that the one used in this example this will not influence the result very much. Cellulose in the form of paper will contain fillers and binders and is therefore only an approximation. Cellulose in the form of wood will always contain water and some other substances, and therefore only represent an approximation.

If enough oxygen isn't available the combustion will be incomplete and carbon monoxide will be formed. Most fuels contain sulphur and nitrogen and these substances will be released as oxides.

As shown in Table 2.3 it is coal that has the biggest sulphur content percentage of almost 10% of the total content of coal.

Table 2.3 Sulphur contents of various fuels

Fuel	Range %
Coal	<=10
Heavy residual oil	0.5-4
Blended resuduals and crudes	0.2-3
Diesel fuel	0.1-0.8
Unleaded gasoline	0.015-0.016

Fuels contains up to 2 % of nitrogen with will be oxidised to NO or NO_2. At high temperatures also some of the nitrogen from the combustion air is also oxidised to nitrogen oxides.

Some of the important mechanisms for the four mentioned gasses are shown in Table 2.4.

Table 2.4 Summary of the most important mechanisms and their governing parameters that control the amounts of frequent LCI emissions (Gabel, K., Forsberg, P. And Tillman, A.M., 2004).

Substance	***Primary emission mechanism***	***Reduction in process***	***End-of-pipe measures***	***Goveming parameters***
Carbon dioxide CO_2	Combustion, calcination	-	Sequenstration (Stationary units)	Carbon content, combustion efficiency
Carbon monoxide CO	Combustion (incomplete), leakale	Oxidation	Catalytic reduction	Excess air, Combustion effeiciency (time, turbulance, temperature
Sulphur dioxide SO_2	Combustion, roasting	Neutralisation (by basic particles)	Adsorption, Absorption	Sulphur content in fuel, effeiciency in air pollution control system (APCS)
Nitogenoxides NO, NO_2	Combustion	Process measures (decrease temperature in flame, decrease oxygen concentration)	Catalytic reduction (SNCR, SCR)	Combustion characteristics (time, turbulance, temperature) Nitrogen in fuel

2.2.2.2 Carbon dioxide uptake

When the clinkers are used and the concrete is mixed the calcium oxide reacts with water forming calcium hydroxide. As the water evaporates the concrete will slowly start to absorb carbon dioxide from the air. This carbonisation is not wanted from a technical point of view, but from an environmental point of view it is important.

No data is available to assess the CO_2-uptake, and therefore it has not been included in any LCA-studies.

A Nordic project has started in 2004 with the goal to develop guidelines for how to assess the CO_2-uptake during the use-stage of a construction and in the demolition-stage. The plan is to set up a practical guideline for companies and LCA-Practitioners and to document this based on actual measurements. Also an estimate for the CO_2-uptake in whole construction mass in the Nordic countries will be provided.

The project is carried out by the major parties in the industry in the 5 countries and representing both research-institutions as well as manufactures. The project will be completed in 2005.

2.2.2.3 Leaching

In the study by (*Schuurmans, 2002*) leaching figures from usual leaching tests are used to investigate the influence of emissions to water and ground in the use stage of concrete structures (tunnel and road) and products (roofing tiles).

Is it clear that the use stage (leaching) contributes significantly, even more than maintenance. This is mainly due to the ‘ecotoxicity’ effect. (The waste stage does not contribute since recycling is assumed instead of landfill). For tunnels the effect of leaching is less important, but still relevant. A similar conclusion was found for concrete roofing tiles.

The leaching effect in the LCA is caused by heavy metals (road and tunnel), probably from cement and aggregates, and by barium (from cement) and PAH (**P**oly**a**romatic **h**ydrocarbons, probably from colouring agents) in the roofing tiles.

Although these concrete products by far meet the legal requirements (and the legal requirements assume a minimum of local environmental impact), leaching is important in LCA, where the global ecotoxicity effects are considered.

It is acknowledged furthermore that landfill of concrete definitely has resulted in leaching of substances. Examples can be found in (*Sloot, H.A. van der 2000*), the Swiss BUWAL liste (1996), (*Sloot H.A. van der, 1996*) and (*IAWG, 1997*). In (*FIP, 2003*) a state-of-the-art overview on leaching from concrete is supplied. Cluster 1of the Eco-Serve project deals specifically with this topic and will further elaborate the issue in relation to sustainable concrete.

From the viewpoint of LCA as well as regarding it as a local environmental issue, leaching could be an appropriate parameter/indicator for developing environmental criteria of cement-based products, with focus on alternative fuels and raw materials in the manufacture of cement production.

2.2.3 LCA-studies regarding pavement

In several countries LCA studies for pavements are performed. The results are often reported in national languages. The results of the studies are in line with other LCA studies of concrete.

A study on Life Cycle Inventory of Asphalt Pavements was completed by IVL (Swedish Environmental Research Institute) in 2000 (*Stripple, 2000*). In this project the system for assessment was defined, a computer model was developed and tested on several examples. No general conclusions was presented, but is was pointed out that the most important factors for the results are design, availability of materials, traffic and climate.

Another study on LCA and pavements was carried out by CBI (Westling, 1999). Conclusions from this report is the following:

- Life cycle costs (LCC) of road pavements show that in a long time perspective concrete pavements are often more economically than asphalt pavements.
- The results from life cycle analysis (LCA) for roads, including traffic, show that the fuel consumptions stands for 90 % of the road's total impact on the environment. Lightning (5 %) and the pavement material (5 %) stand for the rest of the environmental impact. The results from the conducted LCA of roads show that concrete pavements have equal or lower impact on the environment than asphalt pavements.

Other studies and models has been developed. Some are based on statistic input/output model (for instance Conway-Shempf).

For most of these studies the focus on leakage has been very limited or missing. Basically this is because it is very difficult to assess chemicals in the general methods for LCA.

2.2.3.1 Life cycle assessment of roads

In co-operation with the Swedish National Road Administration, the Swedish Environmental Research Institute (IVL) has performed a basic life cycle assessment covering the inventory part for road construction, road maintenance and road operation.

In the study three different road surface materials are analysed: concrete and two types of asphalt depending on its construction process. The asphalt processes analysed are a conventional hot method where the asphalt is heated and mixed with stone material and a cold asphalt process where the asphalt is mixed with water to an emulsion and then mixed with stone materials. In addition, two different engine alternatives for vehicles and machines used in the processes, conventional diesel engines and modern low emission diesel engines, have been studied.

The total energy consumption in construction, maintenance and operation of a 1 km long road during 40 years has been calculated to 23 TJ for an asphalt surface and 27

TJ for a concrete surface where the energy differences are small for the hot and cold asphalt methods. Of the total energy consumption, the 40 years of operation accounts for a large part of the consumption. This energy consumption originates from
consumption of electrical energy from road lighting and traffic control (approximately 12 TJ) i.e. nearly all of the energy consumption for the operation of the road. An equal intensity of lighting has been assumed for asphalt roads and concrete roads. A brighter road surface can however require less illumination intensity and thus a reduced use of electric power. The difference in energy consumption for a conventional diesel engine and a low emission diesel engine is small and thus shows no significant difference in the total energy consumption.

Due to the construction process (not further specified in the study) the energy consumption of a concrete surface lies about 15 % higher than the energy consumption of a asphalt surface. (see figure 2.1)

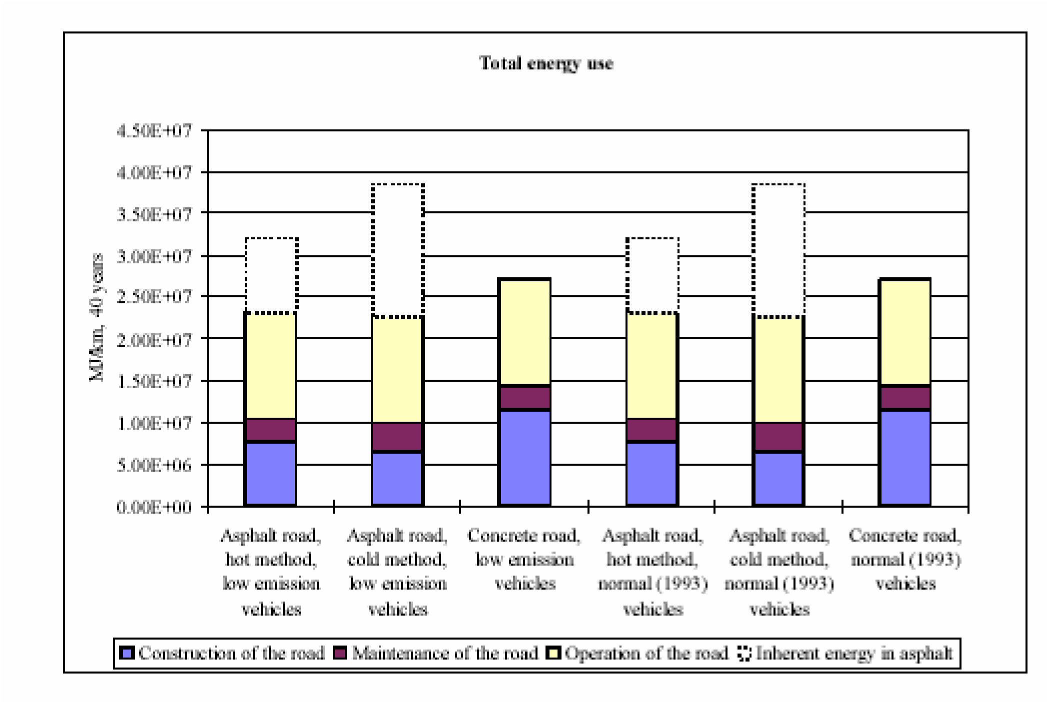


Figure 2.1 Total energy consumed for three different road surface materials and two different engine alternatives for construction vehicles divided into road construction, road maintenance and road operation for a 1 km long road during 40 years of operation. Dotted lines show inherent energy bonded in the road materials but not released as energy. Of the energy used for operation, approximately 12 TJ is consumed by road lights and traffic control

Regarding the emissions of NO_x, SO_2 and CO_2, these are dominated by the emissions from the construction of the road. This is perhaps most relevant for the emission of CO_2. The maintenance of the road constitutes one of the largest sources of emissions and for the NO_x emission, it constitutes a significant part. The operation of the road stands for only a small part of the emissions. This is because electricity production in Sweden mainly us hydro and nuclear energy, which have low emission levels of the traditional substances.

2.2.3.2 Life Inventory analysis for Bitumen the eco-profile

Besides the LCA studies of complete pavement construction, LCA studies of the materials used in the pavement constructions are performed. Since much information on concrete and cement is already included in this report, here we focuses on asphalt.

In 1999 Eurobitume started a project with all the bitumen producers to make an eco-profile for a typical European paving grade bitumen. *(Eurobitume, 1999)*
The reasons for making an average profile and not to have tens of different profiles were several:

- To involve all the producers in the process and to teach the LCA methodology .
- To have the same methods and principles when making eco-pro. les.
- To save resources, especially at the data collection stage.
- To prevent unsound competition with eco-profiles made with different principles.

2.2.4 Studies regarding aggregates

Although from the LCA reports being studied on concrete production it is concluded that aggregates have less or barely any impacts for the total environmental performance of concrete, but several points should be focused and elaborated furthermore:

- Extraction of mineral/ raw materials for aggregates
- Land Use impacts on aggregates extraction
- Recycled aggregates- in accordance with construction and demolition waste

J Broers (2002) provides land use intervention data for aggregate extraction in the Netherlands. The journal "Utilisation of aggregate materials in road construction and bulk fill" summaries ongoing research at the University of Nottingham, UK, which addresses both of these issues for aggregates used in road construction and bulk fill. It also gives addition information on the CoURAgE project (European-wide research collaboration, centred at Nottingham) which has investigated possibilities for optimising the use of aggregate materials in unbound layers of roads.

In a project for the Danish Forrest and Nature Agency the possibilities for sustainable utilisation of aggregates in the future are studied (*Berring A. et al, 2002*). The objective for the study was to establish a technical background material for future regulations. The reports include a mapping of the available resources and an assessment of the situation in the future.

The main findings in the study were that:

- Materials of secondary quality may be used according to coming EU-standards
- Materials from lakes may be used instead of materials from hills ect.

- Materials such as stones and rock may be imported due to lack of necessary resources in Denmark.

2.2.4.1 Extraction of mineral/raw materials for aggregates

The European Conference on Mineral Planning held in Zwolle, The Netherlands in 1997 focused on sustainable mineral aggregate extraction. On one side there is a demand for sufficient construction materials such as sand, gravel and clay and on the other side there is a growing resistance against excavation-works for this raw materials. It has become a big problem in Western Europe that the landscape suffers and nature is also affected (*Molen et al, 1998*).

Many efforts have been formulated in order to find alternatives regarding mining for aggregates need, to name few: aggregates quarries in Iceland, marine sand and gravel mining in North-west Europe, underground mining of rock materials, recycling approach for construction and demolition waste, etc.

Here are some conclusions derived from the demand and supply of aggregates formulated from the previous readings:

- Alternative ways could for instance be the underground excavation of rock for crushed aggregate and subsequent utilisation of stoping areas for waste depositing. (*Nielsen K. and Myrvang, A., 1998*).
- As a result of the growing numbers of possibilities on supplying the aggregates for long-term purpose, it must be followed by an adequate environmental impact assessment, to evaluate the properness of implementing the new system.

As last remarks related with mineral planning in Europe, the following statements could be formulated:

- Mineral planning of aggregates is a local and strategic issue. It has to be recognised that in certain circumstances it may be preferable to restructure patterns of mineral consumption than to attempt to restructure the environment (*Cowell, R., 1998*).
- Although raw material extraction is only a temporary intervention since the affected are is restored during and after the excavation, even so raw materials extraction can not take place wherever raw materials deposits exist. The capability of the area concerned must be assessed and evaluated, to determine if and under which aspects of the various interests excavation is possible (*Schulz, M.,1998*).
- In order to make a closed life cycle approach towards sustainability in building construction, the material chain, has to be assessed. This includes that production process-product-waste, and the accompanying emissions, has to be pursued. The goal is to limit and in the end eliminate the use of raw materials that needs excavation which over-burdened the land and polluted the environment.

2.2.4.2 Land Use impact of aggregates extraction

From a report on assessment of land use of *Broers, J. (2002*) it resulted that the impact of land use could be used to assess the aggregates environmental load. Taking renaturation as the framework, with land use occupation and transformation as the methodology of assessment, this might be possible.

Broers showed the change from before to after a process and it was shown that renaturation time, biodiversity and biomass could be taken as indicators. Problems could be that impacts are very dependant on place and time of the intervention. All biodiversity and life support indicators for land use will suffer from this natural variation to a certain degree. For aggregate extractions, one can hardly speak of ecological recovery, as the situation before and after is so different.

What ecological (development) potentials will result depend mainly on:

- the remaining soil type (the 'substrate');
- the depth of the pit after extraction has ended (relative to surrounding ground- or surface water);
- the remaining relief and steepness of the talud;
- whether a natural development is allowed or whether recreation, recultivation or a specific nature type is pursued.

.

2.2.4.3 Recycled aggregates

A recent study (*Dawson and Mundy, 1999*), has revealed that across Europe an estimated 750 Mt/yr are consumed in the unbound layers of roads — which might suggest a total annual consumption of aggregates by roads of around 1 billion tonnes in Europe.

The use of these alternative aggregate materials as a substitute for primary materials results in multiple environmental benefits including:

- a reduction in primary quarrying activity (reduced noise, dust and land consumption);
- a reduction in development of new waste stockpiles and reuse of material in existing piles;
- clearance and reduction of derelict land generated through waste disposal;
- economical disposal or recycling of marginal materials; and
- a reduction in the utilisation of finite natural resources (*Nunes, 1997*).

Given the load capacity requirement by the pavement surface, alternative aggregates are most likely to find use in the lower layers of pavements. In this role their consumption will be high (due to the volume of material in such layers), but absolute strength will be less important than a good stiffness in spreading traffic loading efficiently to the underlying subgrade soil.

According to *Hill A.R.,et al. (2001)* it was estimated that European pavement construction could be saving of the order of 3.5 billion Euros per annum, taking reasonable assumptions about usage in construction and reconstruction, if appropriate steps along the lines just indicated were employed. These savings do not include the additional benefits, which would result from the reduction in environmental impact if industrial residues were used so that conventional aggregate quarrying and dumping of wastes are both reduced.

2.2.4.4 Sand in concrete

An LCA based on the use of finer sand in concrete is availeble *(Schuurmans et al., 2003*). The application of finer sand in concrete requires adaptations in the concrete's composition (extra cement, extra superplasticizer, or other aggregates) to maintain processability. In order to examine if these adaptations result in shifts from (the proposed) land use effects to other environmental effects, an LCA of finer sand in concrete was carried out.

Besides the common CML-method, an experimental characterisation method for land use, developed by Lindeijer, was applied (*Broers, 2002*). The results show that the application of finer sand indeed results in lower land use effects. The result of LCA of finer sand in concrete shows that hardly any negative environmental effects are anticipated when finer sand is used, provided that the concrete composition is corrected by adding superplasticizer only. Other corrective measures will lead to an increase in environmental impacts.

The decision-maker ought to be aware of the experimental character of the land use impact assessment method, as well as the fact that marine systems cannot be fully assessed on land use effects. Furthermore, it is important to realise that the current situation has been studied and therefore the impact of exploiting new extraction sites or a shift in the yield of existing extraction sites could not be assessed. For the same reason a shift in the price of (fine) sand, which would have an effect on the economic allocation of environmental impacts, could not be taken into account.

It can be concluded that the winning of aggregates and admixtures production hardly influence the environmental effects, except for the transportation of aggregates. On the other hand, it promotes an environmental problem locally. The land use problem gives challenge for many EU countries. From the LCA of finer sand in concrete, it can be concluded that many efforts have been given to minimize the use of land and not to generate new environmental problem. As for aggregates, to lower the land use effect derived from it, recycling is one of the solutions as well as government policy compliance, to reduce virgin material extraction from land. As a result aggregates could be formulated as one of indicators, which contributes to environmental impacts of concrete.

2.2.5 Databases

Many tools for LCA exist in Europe today. Among some of the international recognised systems are SigmaPro, GaBi and EDIP. All the systems consist of a mapping tool, a characterisation and an evaluation tool as well as a database.

The mapping tool includes how to describe inputs and outputs for a product in its relevant life cycle stages and this is in principle the same for all systems. On the other hand, the characterisation and the evaluation tool may vary and give different results depending on the system. The databases can be of different quality and include average data from industry as well as site specific data. The age of the data may also vary.

Many tools can be used for good and valid LCA's in the concrete industry, - all depends on exemptions and limitation in how the product is described and the quality of the data used.

2.2.5.1 ECO-CONCRETE

The European Joint Project Group, which was mentioned earlier in this report, produced an LCA software tool called EcoConcrete. EcoConcrete is a brand new, tailor-made, interactive, learning and communications tool. It has been made especially for the cement and concrete sector in Europe. The purpose of this interactive Excel-spreadsheet based tool is to perform LCA-calculations for a fixed range of concrete products and has a certain degree of freedom.

EcoConcrete is not for sale. The six European branches have decided only to license those people who have passed a kind of exam. Those how have passed the exam, are allowed to use the EcoConcrete tool and will be asked to train six other people. And so on. This is to maintain a level of professionalism that is required to perform LCA-studies.

According to (Lanser, P., Seminar 'Concrete for the environment', April 9 2002 Stockholm Sweden), EcoConcrete is the best environmental info that you can have on concrete today. In the LCAs that were performed to build up the database and the tool, ten functional units have been assessed, in the field of concrete piles and bridges, floors, paving bricks and walls. These functional units are examples. The described concrete applications not always are representative for Europe as a whole. The constituents of the concrete are supposed to be representative, but this is not always the case for the application itself. There is no such a thing like a European pavement brick.

EcoConcrete is not meant for to comparative assertions, but for learning purposes within industry, developing life thinking and using it if necessary against unwarranted denigrations from competitors.

2.2.5.2 Dutch LCA concrete database

Among others the Dutch LCA concrete database is developed by a platform of concrete organisations (Betonplatform):

- Stichting Zand (sand association),
- Stichting Grind (gravel association),
- VNC (association of Dutch cement industry),
- VOBN (concrete ready mix association) and

- BFBN (precast concrete association).

It contains LCI data from concrete constituents, concrete production and concrete products for housing. Furthermore, the software exists of a ‘script’ tool, helping the user to carry out a proper LCA. The database and script are developed in the LCA software SimaPro. Many if not most, LCA studies on concrete in the Netherlands are based on these data.

2.2.5.3 A Manual for the concrete industry

A manual for gathering data for environmental assessments was prepared in 2000 for the Danish Concrete Industry (Glavind M and Riis K, 2000). The manual includes an introduction to LCA, a description of important data, examples and a PC-tool for gathering data. Four companies tested the manual in order to ensure that the result was easy to implement in industry.

2.2.5.4 LCA-Tool for the construction Industry

The Danish Building and Urban Research Institute has developed at PC-tool named BEAT 2000, which includes a database and a PC-tool for environmental assessment of a construction in its life cycle. The tool can be used for a single product or element or for a complete construction. The basic method used assessing the findings is the Danish EDIP-method. Further information can be retrieved at www.dbur.dk/english.

2.2.6 Summary

General findings from the LCA-studies show that the main hot spot in the life cycle of a concrete product is use of energy for heating and cooling purposes as well as the production of clinker and the content of cement.

In Eco-Serve focus is not on the use-phase, where most of the energy in whole life cycle is spent for heating and cooling.

Focus has been directed towards the energy consumption and the emissions of carbon dioxide from fossil fuels and the calcination of limestone. It is agreed upon that the CO_2 and the contribution to the green house effect are important. Besides CO_2, other emissions such as NO_x and specific (heavy) metals due to clinker production are significant for the environmental impact of concrete.

Transportation over long distances of large amount of materials, which might be relevant for aggregates, has also been addressed.

Small amounts of environmental hazardous substances may be introduced into the concrete from the cement, fillers or aggregates. If, for instance, alternative fuels are used in the cement production, this may lead to an elevated content of heavy metals, which may be spread in the environment by leaching. Fillers and aggregates can introduce other environmental negative impacts.

In several countries LCA studies for pavements are performed. The results of the studies are in line with other LCA studies of concrete. In some studies concrete is compared to asphalt and in specific examples concrete is preferred based on some selected parameters.

Concerns have been directed towards the land use when excavating aggregates. It is concluded that no good method for assessing this issue is available.

Recycling of concrete and the use of recycled aggregates is another topic in the environmental discussion of concrete and aggregates. This discussions focuses on land use impacts due to aggregate production and waste minimisation of concrete.

Assessments of admixtures have not been included in the LCA-studies. It is expected that this is because the LCA-methodology handles chemicals in a very poor way and that an assessment of chemicals requires a number of data, which normally not is available.

3. Methods and principles used in Task 2

In this chapter is presented the methods and principles used for selections of indicators, issues related to data and general tools used.

3.1 The general approach

To meet the objectives of the Eco-Serve project the goal is to measure improvements with respect to

- environment
- working environment
- productivity

in a life cycle perspective of the construction. The measurement will be carried out in terms of key indicators

Environmental assessments are in general carried out in two ways:

1. Life Cycle Inventories (LCI), where all input- and output-streams are mapped as amounts and types of materials.
2. Life cycle Assessment (LCA), where a number of environmental effect categories are estimated based on the result of the LCI.

The result of an LCI can be complicated to evaluate, because of the many data on inputs and outputs. On the other hand, there is international consensus of how to carry this out according to SETAC and the ISO-standards.

The results of an LCA consist of less data, because all inputs and outputs are transformed into environmental effect categories. There is internationally consensus of how to estimate some of the environmental effect categories, for instance the green house effect and ozone depletion. Other effect such as toxicity, the effects from waste and land uses are still discussed.

Therefore, in this project, indicators are based on an LCI. The indicators are chosen among the essential input- and output-streams and will be in a number that are possible to assess.

3.2 The four clusters

The four clusters represent important parties in the construction industry and in a life cycle perspective they are related to each other. This is shown in Figure 3.1.

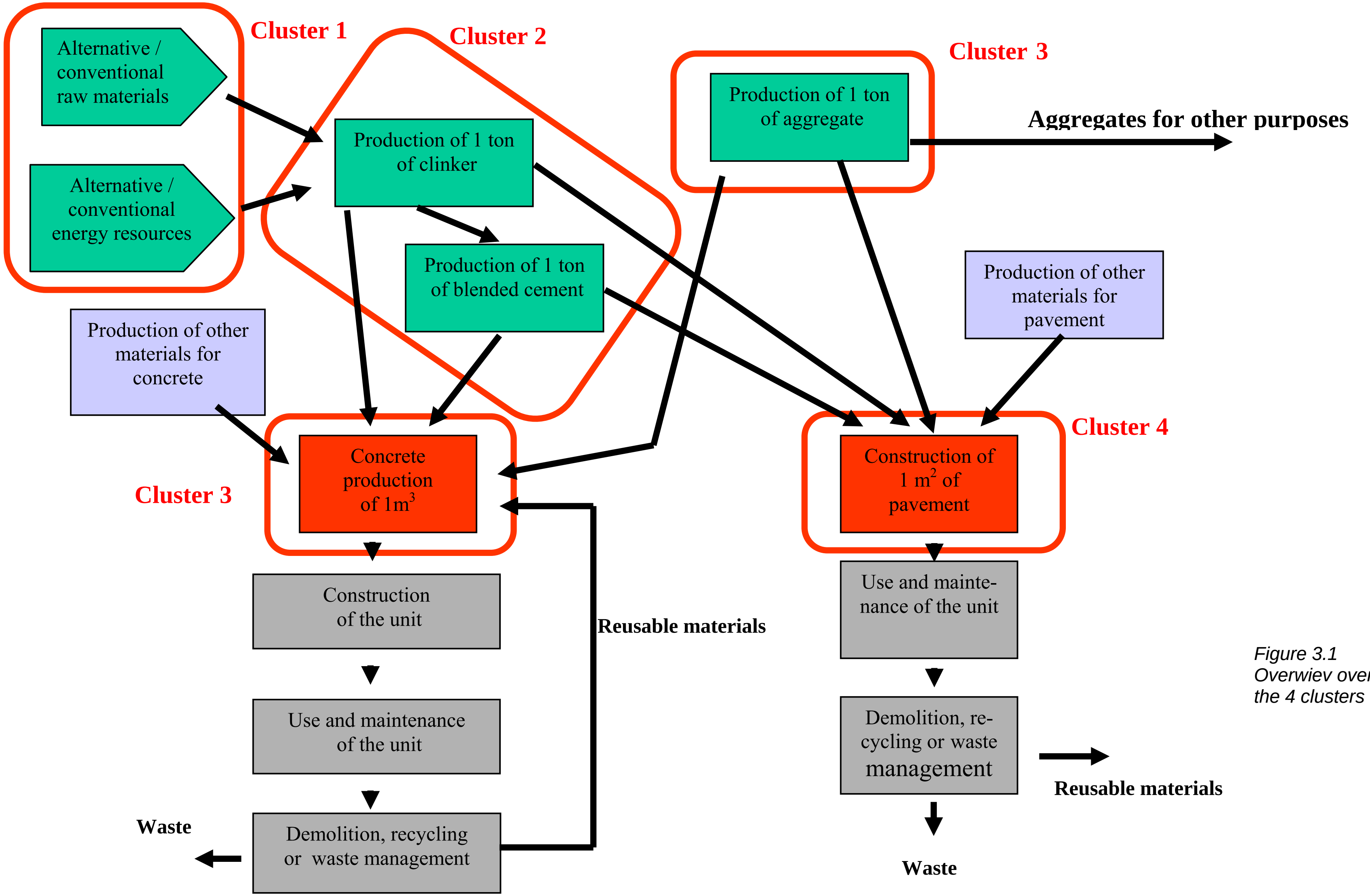


Figure 3.1 Overwiev over the 4 clusters

As shown in Figure 3.1 functional units are defined for two product types, - a production of 1 m^3 of concrete and construction of 1 m^2 of pavement.

Cluster 3 covers concrete production and here it is important to define the functional unit. Cluster 4 covers the other functional unit, - production of concrete pavement.

The materials used for producing concrete for a building and concrete pavement are partly the same. In both productions aggregates (cluster 3) and blended cement or clinker (cluster 2) are used. Other materials used are not included in this study.

Fuels and raw materials for the clinker production is covered by cluster 1, where the use of waste and other alternative materials for energy production is in focus.

Figure 3.1 also illustrates that the construction, the use phases building and the pavement as well as the demolition, recycling and waste treatment are not included in the technical part of the Eco-Serve project. It is included in the environmental assessment if changes in the life cycle stages, that the clusters cover, have any effect on the other stages of the life cycle.

The activities in the four clusters are very different technologically. Therefore the parameters or indicators to measure any changes with respect to the environment may be different.

The goals for the indicators are:
1. To measure and document improvements related to a specific activity in an easy way and,
2. To evaluate the effect of a certain change and document effects in all life cycle stages.
3. For communication purposes

The first goal will advocate for different indicators that might not be able to be added together and provide an assessment for the whole life cycle.

While it is desirable to provide a benchmarking tool, it will be necessary that at least some of the indicators are the same for all clusters.

3.3 LCA and the construction industry

Several life cycle assessments have been carried out over the past decade. Common and necessary for then all is to define the tree basic issues:

- the purpose of the study
- the functional unit
- system boundaries, limitations and exemptions

3.3.1.1 The purpose of the study

Before a study is stated some one or a few simple questions have to be defined (*Pommer et al, 2003*). A question might for instance be "Has building part A less impact on the environment than building part B?, - both can give you the same technical service." Another question could be " Is production method A for concrete with a certain technical specification more environmental friendly than method B.

Both questions can only be answered if the term "Environmental Impact" is defined. Depending on what the answer shall be used for, a different set of environmental indicators or impact categories can be chosen.

For internal use in a company, for instance in product development, one or two parameters are practical and sufficient. On the other hand, for basic documentation for public uses all types of impact on the environment have to be taken into account.

So the first step in an environmental assessment is besides defining the purpose of the study also to identify what the study shall be used for and what amount of resources (time and money) are available.

Often is distinguished between general and specific aspects. Focus is often on general aspects such as:

- Which sources generate the environmental impact?
- Which life cycle stages do we need to focus on in order to minimise the environmental impact?

More specific aspects could be:

- Would it be an advantage to change from product A to product B ?
- Will the environmental impact be less if we use type A of concrete iron instead of type B?
- Will the environmental impact be different if filler type A is used instead of filler type B?

For both types of questions it is necessary to clarify what the answer to the question shall be used for and the amount of resources that is available. This will give an indication of the type of assessment that needs to be carried out.

3.3.1.2 The functional unit

The functional unit is the key definition in any assessment study. The functional unit defines the services the product can give. You can only compare two products with the same functional unit.

The service that defines the functional unit includes three parts:

1. A quantity (amount, volume, etc)
2. A duration
3. Qualities/properties

For instance, in the case of a pipeline for waste water tubes can be made of concrete or plastic (PP). Then the functional unit can be defined as 100 meters of tube with the capacity of x m^3/hour.

The lifetime also has to be defined. Often two products do not have the same lifetime, so maybe in 80 years 2 tubes of concrete are necessary compared to 1 of plastic.

Often other properties are important. For instance it might be relevant to look at the weight and the size of the tubes as well as necessary maintenance.

In general, when related to the construction industry the functional unit will be a product for a specified construction, - the size, the lifetime of the construction and technical properties, that defines environmental class, strength and other relevant parameters.

3.3.1.3 The system

It is also necessary to define the life cycle stages of the product "from cradle to grave". In general this can be illustrated as in figure 3.2, General life cycle of concrete.

In Figure 3.2 the functional unit is shown in bold notation in the beginning of stage IV.

(I) raw material acquisition	Mining of limestone for cement Mining of aggregates
(II) production of materials	Cement production: Clinker production Cement grinding Production of additives Production of water Transportation of aggregates, cement and additives to concrete plant Concrete production
(III) construction	Transport of concrete to site Construction activities
(IV) use and maintenance of structure	(processes dependent on the structure; only material related processes are considered)
(V) demolition and waste treatment	Demolition Transport of rest material Landfill, recycling to concrete aggregate, or reuse

For all the boxes shown, it has to be defined what is included in each, - what inputs that are relevant in term of materials and energy and what outputs that are relevant in terms of emissions to air and water as well as waste.

By defining the system and evaluate available data it will give an indication of necessary limitations and exemptions.

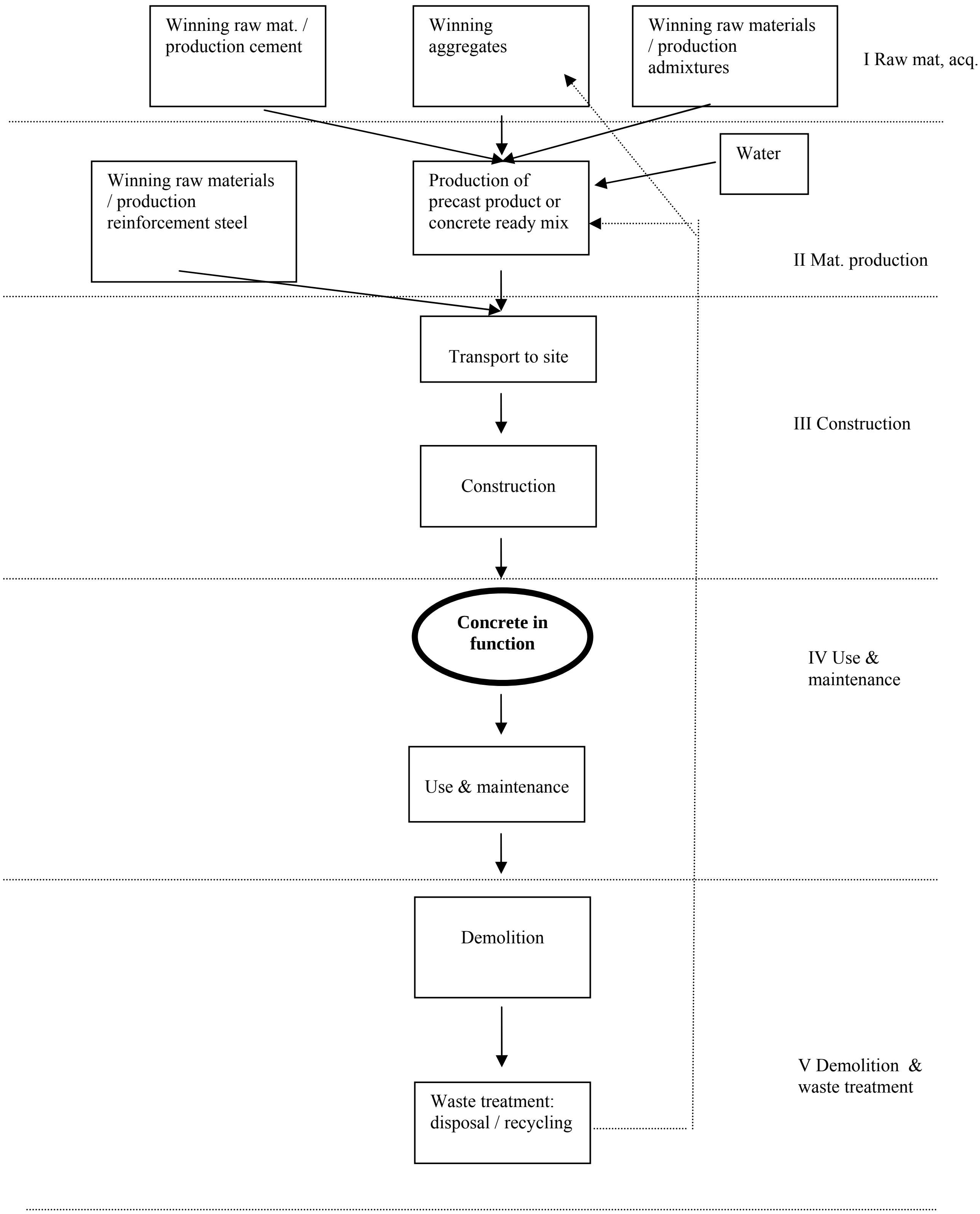


Figure 3.2 General life cycle of concrete

3.4 Indicators

Even when the main focus is on environmental indicators, indicators for measuring the performance in the working environment and productivity are considered as well. Here the term productivity includes quality, competitiveness as well as costs.

In the following, general aspects of using indicators as well as possible indicators for the concrete industry are discussed. In this section, no considerations regarding the availability of data etc. are taken into account. This section is solely meant to provide a general background for the choice of indicators made by the industry.

3.4.1 Important parameters

3.4.1.1 Function

An indicator is a sign or signal that relays a complex message, potentially from numerous sources, in a simplified and useful manner (Environmental Protection Agency, 2000).

Moreover, the primary uses of an indicator are to characterise current status and to track or predict significant change. Indicators help to measure changes and progress in an increasingly complex field of private, commercial, and political decision making towards sustainability.

According to *Jasch, C., (2000)* indicators are used to depict the vast quantity of environmental data of a firm in a comprehensive and concise manner. They are mostly applied to set absolute material and energy data in relation to other variables, in order to increase the informational value of quantitative data.

In order to establish indicator systems, with regards to different functions of indicators (policy development, enforcement monitoring, state analysis), there is probably no single optimum system of indicators.

Three main purposes regarding the use of indicators, as well as their requested qualities can be identified (*Spangenberg, J.H., et al. 1998*):

- Summarising analysis: all indicators must be based on world-wide-recognised methodologies and valid data. The number of such indicators will usually turn out to be comparably high, in order to cover all relevant aspects in sufficient detail.
- Political guidance: indicators should provide links with players, causes and instruments. A limited number is necessary in order to establish a proper link to policy decision arguably.
- Communication: vivid, easily understandable indicators are needed. However, there should be as few as possible, possibly only one to be used as a central communication tool.

3.4.1.2 Expression

According to Jasch (2000) data used for environmental performance indicators can be expressed as absolute or relative measurements, and, depending on their use and application, can be aggregated and/or weighted. Indicators can be classified as follows:

- absolute indicators; e.g. tons of raw material, emissions, taken from input–output analysis;
- relative indicators, where input figures are referenced to other variables such as production in tons, revenue, number of employees, office space in m^2; e.g. water per hectolitre beer, detergent per m^2;
- indexed indicators, where figures are expressed as a percentage with respect to a total, or as a percentage change to values of previous years etc.;
- aggregated depictions, where figures of the same units are summed over more than one production step or product life cycle;
- weighted evaluations, which try to depict figures of varying importance by means of conversion factors.

Data could be collected at any level but normally the reference unit should be production unit.

3.4.2 Environmental indicators

In Spangenbergs report is found the following statement by the Executive Director, European Environment Agency:

> *"Environmental Indicators enable a clear information exchange regarding the issues they address. They serve to supply information on problems enabling policy makers to appreciate the seriousness of environmental problems, they support policy development and priority setting by identifying key factors that cause pressures on the environment. Finally they serve to monitor the effects of policy responses and allow the public to follow and participate in the process, making it more accountable."*

ISO 14031 (ISO 14031:1999) on Environmental Performance Evaluation elaborates the concept of environmental indicators. Based on the research on the ISO 14031, environmental indicators have the following purposes:

- comparison of environmental performance over time
- highlighting of optimization potentials
- derivation and pursuit of environmental target
- identification of market chances and cost reduction potentials
- evaluation of environmental performance between firms (benchmarking)
- communicational tool for environmental reports
- feedback instrument for information and motivation of the workforce
- technical support for the EU-EMAS Regulation and ISO 14.001.

Benchmarking within a branch offers the opportunity to identify weak points and potential improvements.

Principles for the derivation of environmental indicators also laid down in the standard are:

- *Comparability*:
  Indicators must be comparable and reflect changes in environmental performance;
- *Target-orientated*:
  Selected indicators must be chosen so they can act towards goals which are able to be influenced by the firm;
- *Balanced*:
  Indicators must reflect environmental performance in a concise manner, and display problem areas as well as benefits in a balanced manner;
- *Continuity*:
  For sake of comparison, indicators must be derived the by the same criteria and relate to each other through corresponding time series and units;
- *Frequency*:
  Indicators must be derived frequently enough (monthly, quarterly, yearly) so that action can be taken in due time;
- *Comparability*:
  Indicators must be understandable for the user and correspond to his information needs. The system has to be lucid and concentrate on the most important figures.

3.4.3 Potential environmental indicators for the construction industry

The European Network CRISP (Construction and City Related Sustainability Indicators, EC Proposal Contract N° : EVK4-CT-1999-20002) aims to co-ordinate current research work defining and validating such indicators and implementing them to measure the sustainability of construction projects (buildings and built environment) in cities.

This includes the activities of identifying and maintaining indicator sets together with implementing them to compare sustainability at a number of levels: individual buildings, large groups of buildings at both the urban and suburban levels as well as for whole urban areas. Implementation in construction activities at the scale of a city, a region or a country is also to be explored.

The following is a list of identified indicators for building products.

Source: http://crisp.cstb.fr/ List of September 18, 2003

Name :	Corresponding system(s) :
Radioactive waste	Hammarby Sjöstad ...
Stratospheric ozone formation	Hammarby Sjöstad ...
Products promoting sustainability	The European Common Indicators Set ...
global warming	Ecodec ...
ozone depletion	Ecodec ...
reuse/recycle	Ecodec ...
total energy consumption	Ecodec
fossil energy consumption	Ecodec
Embodied emissions of materials, annualized over the life-cycle	Green Building Challenge (GBC) ...
Typical service life	French standard system ...
Total primary energy	French standard system ...
Renewable energy	French standard system ...
Resources consumption	French standard system ...
Climate change	French standard system ...
Atmospheric acidification	French standard system
Stratospheric ozone depletion	French standard system ...
Non energetic resources consumption	French standard system ...
Climate change potential of building products	RT Environmental declaration ...
Consumption of non-renewable energy	RT Environmental declaration ...
Consumption of renewable energy	RT Environmental declaration ...
Consumption of renewable material resources	RT Environmental declaration ...
Service life	RT Environmental declaration ...
Exhaustion of resources	MRPI: Environmentally Relevant Product Information
Emissions	MRPI: Environmentally Relevant Product Information
Energy	MRPI: Environmentally Relevant Product Information
Climate Change	Green Guide to Specification; Green Guide to Housing Specification ...

Fossil Fuel Depletion	Green Guide to Specification; Green Guide to Housing Specification
Ozone Depletion	Green Guide to Specification; Green Guide to Housing Specification ...
Acid Deposition	Green Guide to Specification; Green Guide to Housing Specification
Environmental Impact - Summary rating	Green Guide to Specification; Green Guide to Housing Specification ...
Ecolabel	None
Recycled Label	None
Acoustical Comfort	Healthy Buildings

In the Eco-Serve project absolute and relative indicators are considered with reference to a defined functional unit. Aggregated indicators may be used. This could for instance be if the indicator is CO_2-emissions and the total amount for the whole life cycle id compared to a specific process or life cycle stage.

Weighted indicators will not be used, as there is consensus in the project team that there is not enough international agreement on methods for weightening.

3.4.4 Indicators for the working environment

Internationally accepted indicators for the working environment do not exist. In the following, proposed indicators are related to the working environment in the construction industry. For other industries other aspects are likely to be more important.

Regarding the construction industry and working environment different indicators are important depending on where in the life cycle one focus. The most important and relevant for almost all life cycle stages are:

- Noise
- Vibrations
- Dust
- Accidents

In addition to this workers come into contact with a number of different chemicals, - either by inhalation of vapours or by skin contact. This could for instance be relevant to focus on chromium and eczema, but this is not included here. In some situations radiation is also considered as a parameter; - this is excluded here, because radiation primarily affect people during the use phase of the construction.

In the following the four will be described.

3.4.4.1 Noise

The level of noise in the working area is important for the working environment. The level of noise is measured in dB(A). Also the duration of noise is important.

As a rule of thumb, noise is more than 85 dB(A) if lout talk is not recognised in a distance of 1 meter. In general protective devises are required if the level is higher than 80 dB(A). (*Danish guidelines for the working environment, no. 9*)

As in indication of the level of noise on a construction site some examples are given in Table 3.1(*Hansen and Glavind, 2001*)

Table 3.1: Examples of noise levels at a construction site

<table>
<tr><th></th><th>Ordinary concrete without other ongoing activities

Only rod vibration

Measured</th><th colspan="2">Ordinary concrete including other ongoing activities

Rod vibration and light vibrating screed seperately

Assessed</th><th colspan="2">Ordinary concrete including other ongoing activities

Rod vribration and light vibrating screed at the same time
Assessed</th><th>Vibration-free concrete, with other ongoing activities

Without vibration

Assessed</th></tr>
<tr><td>Background noise</td><td>66 dB(A)</td><td colspan="2">76 dB(A)</td><td colspan="2">76 dB(A)</td><td>76 dB(A)</td></tr>
<tr><td>Proportioning concrete from a truck with concrete chute and compressing</td><td>89-90 dB(A)</td><td colspan="2">92-93 dB(A)</td><td colspan="2">95-96 dB(A)</td><td>89-90 dB(A)</td></tr>
<tr><td rowspan="2">Compressing alone</td><td rowspan="2">81 dB(A)</td><td>Rod</td><td>Screed</td><td>Rod</td><td>Screed</td><td rowspan="2">76 dB(A)</td></tr>
<tr><td>84 dB(A)</td><td>88-91 dB(A)</td><td>87 dB(A)</td><td>91-94 dB(A)</td></tr>
<tr><td>Rod vibrator “in contact” with armouring</td><td>83 dB(A)</td><td colspan="2">86 dB(A)</td><td colspan="2">89 dB(A)</td><td></td></tr>
</table>

As can bee seen from Table 3.1 the level of noise in many situations are above 80 dB(A), and is therefore an important problem in the working environment.

Because the dB(A)-scale is logarithmic, a slightly increase in the level of noise will cause a substantial effect. The effect of increasing noise is illustrated in Table 3.2.

Table 3.2 Effects of noise

Level of noise in 1 hour	Equivalent to hours at 85 dB(A)
85 dB(A)	1 hour
88 dB(A)	2 hours
91 dB(A)	4 hours
94 dB(A)	8 hours
97 dB(A)	16 hours
100 dB(A)	32 hours

A relevant indicator might be:

1. Number of man-hours for which the level of noise exceeds 85 dB(A) at the workplace or

2. Number of man-hours, for which the level of noise above 85 dB(A) at the workplace is based on measurements and estimated as equivalent hours at 85 dB(A).

Taken into account that measurements are not common in all facilities, it is recommended to use no. 1 if noise is chosen as an important indicator.

3.4.4.2 Vibrations

Vibrations that affect the hands and arms are common in the construction industry.

Numbness or tingling feelings in the fingers is the first sign of harmful effects of vibrations. There is a risk of "white fingers" after longer time. "White fingers" causes white, cold and numb fingers in cold weather. Other effects can be permanent reduced sense of touch, pain in shoulder and joints and increased risk of rheumatism.

Vibrations are measured according to ISO 5349 in the unit m/s^2 and are called the intensity of vibration. The vibrations should be minimised as much as possible and not exceed 3 m/s^2. Regulation regarding vibrations has been issued both in EU and in the member states.

Vibrations of 5 m/s^2 will cause that 10 percent of the people will experience White fingers within about 6 years. Vibrations of 3 m/s^2 will cause that 10 percent of the people will experience white fingers in about 10 years. The risk of getting white fingers is almost none by vibrations less than 1 m/s^2.

Besides the intensity of vibrations the time of exposure is also important. The relationship between intensity and exposure time is shown in Table 3.3.

Table 3.3 Effects of vibrations

Intensity of vibrations in 1 hour	Equivalent to hours 3 m/s^2
3 m/s^2	1 hour
4,5 m/s^2	2 hours
6 m/s^2	4 hours
9 m/s^2	8 hours
12 m/s^2	16 hours

In Figure 3.3 Intensity of vibrations and time before health effects occurs.is shown the relationship between intensity of vibrations and the number of years before an effect is recognised.

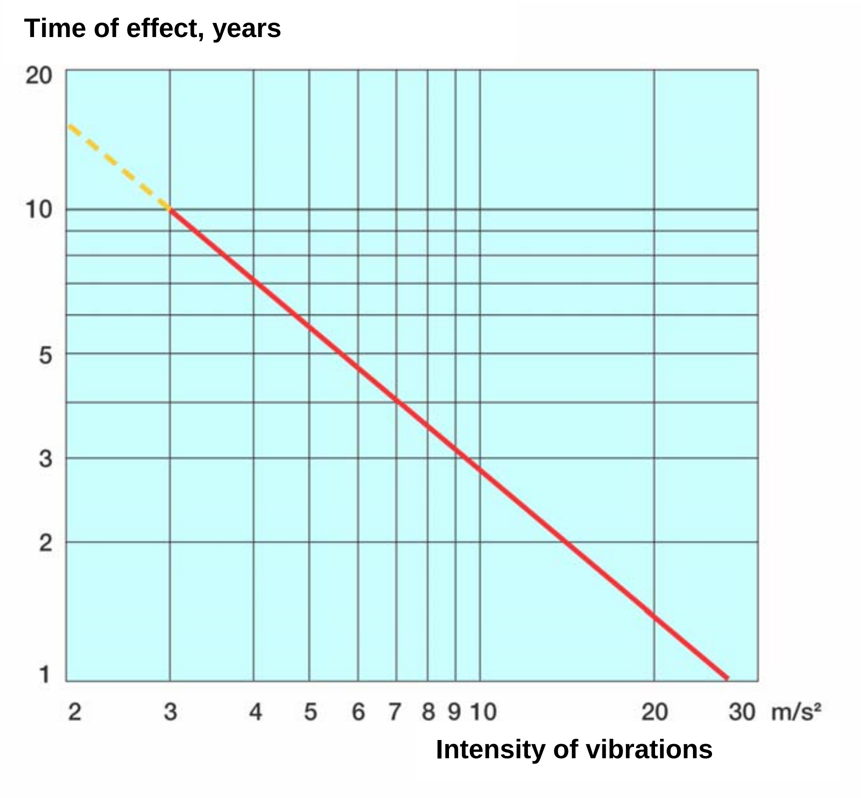


Figure 3.3 Intensity of vibrations and time before health effects occurs.

A relevant indicator might be:

1. Number of man-hours, for which the intensity of vibrations exceeds 3 m/s^2 at the workplace or

2. Number of man-hours, for which the intensity of vibrations is above 3 m/s^2 at the workplace based on measurements or information from the supplier of equipment and estimated as equivalent hours at 3 m/s^2.

Taken into account that measurements are not common in all facilities and that information about the equipment may be absent, it is recommended to use no. 1 if vibrations are chosen as an important indicator.

3.4.4.3 Dust

Dust is a common issue in the working environment of the construction industry. When evaluating the health effects it is important to know the size of particles and what substances the particles consist of.

Dust is present through out the life cycle of a concrete product. This means that dust can come from the extraction of limestone and aggregates, from the production of clinker, from filler materials as well as from demolition. In the different situation the dust contains different substances and might cause different effects.

When evaluating dust there is looked upon the total amount of dust and the respirable part less than 5 micron. In Table 3.4 are shown the major effects and limits for the most relevant types of dust. (Threshold Limit Values (TLV) from international databases, 2004)

Table 3.4: Selected types of dust from the concrete industry

Type of dust	Total amount	Respirable part
Mineral dust, inert	TLV: 10 mg/m^3 Causes irritation of nose, mouth and throat	TLV: 5 mg/m^3 Causes irritation of nose, mouth and throat
Alkaline dust, e.g. calcium oxide	TLV: calcium oxide 2 mg/m^3 Causes irritations, mild to severe of nose, throat, lungs and mucous membranes In severe cases inhalation may cause severe damages to the lungs.	
Quarts	TLV: 3 mg/m^3 Causes irritation of nose, mouth and throat	TLV: 0,1 mg/m^3 These fine particles may be absorbed by the lung tissue and may cause cancer

Key-parameters for dust in the working environment may be the total amount of mineral inert dust and respirable quartz measured in mg/m^3 in the area, where people work.

An indicator could for instance be amount of man-hours exposed to dust above the threshold limits. From a safety point of view, the most important part of the dust is respirable crystalline quartz, which may cause cancer.

3.4.4.4 Accidents

Statistics for accidents are an indicator for risk and safety levels at the workplace. From the English Health and Safety Statistics (2001) indications are:

- Rate of injuries per 100,000 of employees
- Fatal rate per 100,000 workers

Other statistics are expressed in similar terms.

As an example of the rate of injuries and fatal incidents some key-numbers are shown in Table 3.5.

Table 3.5: Examples of the rate of injuries and fatal accidens for selected industries (Health and Safety Statistics, 2001)

	Rate of injuries per 100,000 employees	Fatal rate per 100,000 workers
Quarrying of stone, ore and clay	450	10.4
Construction	392	4.8
Manufacturing of metals and metal products	298	3.4
Agriculture, hunting, forestry and fishing	212	9.0
All industries	113	0.9

As illustrated in Table 3.5, the construction industry has a relatively high rate of injuries compared to the average of all industries. Regarding fatal incidents, the rate for the construction industry is substantially higher than the average, but for instance lower than agriculture.

The two presented indicators could be used as a measure for accidents.

3.4.5 Indicators for productivity

A number of parameters have been discussed in order to find indicators for productivity, quality and competitiveness. In several studies attempts have been made to relate economic issues to environmental performance.

The Benchmark Centre for the Danish Construction Sector has developed a benchmarking system in 2002. Performance Indicators includes indicators for Time, Productivity, Quality, Working Environment, Environment and Costs. Here productivity is defined in monetary terms, based on the difference between the cocts of construction and the costs related to materials, labour and others. The indicator for quality is based on defects and the time required to eliminate the defects. More information can be retrieved at http://www.byggeevaluering.dk/object.php?obj=5e000c.

It is not the objective of the Eco-Serve project to include economic indicators or apply the theory of welfare-economics, but to point out a few practically measurable indicators.

3.4.5.1 Productivity

Regarding productivity an indicator based on used man-hors per functional unit has been discussed. Maybe it is not possible to find actual numbers for this, but measure in a qualitative way could be feasible. A solution could be that one states that technology A requires more or less man-hors than technology B.

3.4.5.2 Quality

Quality can be “measured” in different terms. For instance the number of reclamation’s per 100 units or the number of repairs per 100 units could be a practical way of expressing quality.

Besides quality is partly included in the definition of the functional unit. For instance the expected lifetime is included in the functional unit.

Other parameters that defines quality regarding the construction industry are partly defined by the different strength classes and environmental classes. This information also is a part of the definition of the functional unit.

Besides the above mentioned parameters a number of other aspects can be included defining quality, - but it will depend on the actual product and its life cycle. This is illustrated in the two following examples.

> *A floor in a factory can be made of two different types of cements and aggregates. The surfaces are different and require different surface treatment. The differences will be shown in the description of the life cycle stages for the two products (the floor) and included in the set of environmental parameters.*
>
> *Many people will look upon the design and the way surfaces appear when the construction (the product) is in use. There is no absolute scale for a” nice appearance” or a “good design”. Therefore a measure of quality for such aspects, where you have no objectivity, but only personal opinions, has no meaning.*

Based on the above issues, quality in this project is handled mainly as a part of the definition of the functional unit. Other relevant differences will be included in the description of the life cycle stages.

3.4.5.3 Competitiveness

Competitiveness is primarily based on the actual cost of the product and durability. Other parameters such as reliability of supply can also be relevant.

Data for cost of the materials do exists but this type of information is sometimes regarded as confidential information.

In most situations it will be possible to establish a relative assessment of the cost, - for instance if one technology requires x percent less of a specific material.

Durability should be the same as the constructions lifetime (the product) and therefore be included in the definition of the functional unit. Durability can be looked upon as the actual number of years the construction is used and not the number of years a construction in theory is able to be in use.

If certain requirement occur during the use of the construction in order to meet the requirements for durability, these aspects have to be included in the description of the life cycle stages. This might include different types of maintenance.

3.4.6 Guidelines for indicators

3.4.6.1 Introduction

At the Eco-Serve workshop on the 18th of March 2003, a preliminary discussion took place to prepare for the selection of indicators for each of the four Eco-Serve clusters. The cluster representatives defined a proposal for a functional unit, possible indicators and possible data sources. The preliminary results would be discussed afterwards within the clusters. The task 2 management facilitated this discussion by providing guidelines.

Goal of the guidelines was two-fold:

- to structure and guide the discussion within the clusters;
- to clarify which information task 2 needs from the clusters

During the time after, the four clusters determined the indicators presented in the following chapters.

The next section is a description of the guidelines the clusters used for the first draft of the indicators.

3.4.6.2 Steps in the definition of indicators

There are defined five steps in the process of defining the indicators and mapping these.

Step 1:Goal and scope

1a. Define the central question

Define the central question and the intended audience / target group. In this step the goal of the clusters is described. This corresponds to the problem definition within the clusters. The central question is essential: it must be clear which question has to be answered by the indicators, and for whom.

1b. Define the functional unit

In order to do the mapping, a reference unit has to be defined in which the results are expressed. This is called the functional unit. The functional unit typically contains performance requirements (a function/performance to be fulfilled). The functional unit is the basis for comparisons of technology options.

***Functional unit**: Quantified performance of a product system for use of as a reference unit in a life cycle assessment study. An other way of defining "Functional unit" could be "Basis for comparison of alternative products satisfying the same need"*
Definition of a functional unit is a very important starting point, since it reflects the question to be answered. If the functional unit is not well defined, the mapping will not serve the goal.
Example: 1 ton cement is a poor functional unit, better is to specify the cement type, it's applications and required performance.

1c. Describe the technology options that are mapped

The options that are investigated within the cluster are defined. These should all meet the performance requirements in the functional unit, to make them comparable. Now we know for which options data will be collected to establish an indicator score and to do the mapping.

***Example**: Goal is to find environmentally friendly concrete mixtures (step 1a)*
The corresponding functional unit is 1m3 concrete according to EN 206-1 (step 1b)
Three different mixtures are defined that meet the requirements of EN 206-1 (step 1c).

Step 2 Life cycle definition

2a Draft the life cycle stages

Describe the life cycle of the technology options fulfilling the functional unit. In principle from cradle to grave (but in some cases only cradle to gate can be defined), in the following the five main stages:

(I) raw material acquisition,
(II) production of materials,
(III) construction of structures,
(IV) use of structures – including operations and maintenance (as far as material-related)
(V) disposal or reuse of the structure

2b Important life cycle steps

Determine which life cycle stages could be influenced by the technology options from step 1c, which type of effect (external environment, working environment, economics) is influenced and what is the cause.

Think of all types of effects. For external environment for example you should think of influences on e.g. raw materials use (including water and land), energy use, emissions and waste production. Using Table 3.6 may help.

Table 3.6: Inportant issues

Influence on	External environment (resources, energy, emissions, waste, land use, water use)	working environment	productivity / competitiveness / quality
Life cycle stage	Cause	Cause	Cause
Raw material acquisition			
Material production			
Construction activities			
Use & Maintenance			
Demolition and waste treatment (disposal / reuse)			

Example: A concrete mixtures of step 1c contains aggregates that are transported over a longer distance than usual. The life cycle stage 'raw material acquisition' is influenced, there are effects on the external environment and on economic, the cause is 'transport distance'.
Example: A concrete mixture may influence the durability, or may influence recyclability
Example: The use of an alternative material decreases energy use, but increases NOx emissions (both external environment)

Step 3 Indicators selection and definition

3a Determine important influences

Determine important influences and their interactions in co-operation with task 2
Select the most important causes from the table in step 2. Existing studies (e.g. LCA studies for external environment) can be of help. *Ask task 2 to help in this exercise*.
Interactions should be identified to avoid (or to be aware of) double counting.

3b Select indicators

Indicators are defined for the most important influences. The indicators are based on the causes mentioned in the table from step 2, and can be either physical parameters (e.g. cement content, transport distance, weight); chemical substances (e.g. CO2-emission, amount of waste); or economic parameters (e.g. relative costs, user perception).
Define at least one indicator per target fields of Eco-Serve:

- external environment,
- working environment,
- productivity / competitiveness / quality

Indicator: "Environmental Indicators enable a clear information exchange regarding the issues they address. They serve to supply information on problems enabling policy makers to appreciate the seriousness of environmental problems, they support policy development and priority setting by identifying key factors that cause pressures on the environment. Finally they serve to monitor the effects of policy responses and allow the public to follow and participate in the process, making itmore accountable."

Domingo Jiménez-Beltrán, Executive Director,European Environment Agency
From: **Material Flow based Indicators in Environmental Reporting**, by European Environment Agency, October 1998. Spangenberg, J.H., et al.

3c Define a quantitative unit in which the indicators are expressed

3d If necessary, define the method to determine the value of an indicator

Example: The energy use is influenced during production and during construction, but most during production. Apossible indicator could be the energy use of production (external environment indicator)

Example: The transport distance of a raw material is influenced. The difference is relatively high, but it involves a small amount of material. The decision to include this as an indicator is not based on 'km' but on 't.km'. In case the total influenced t.km is much less than the total t.km, the transport distance is not included.

Example: CO_2 during clinker production and cement content are potential indicators. There is a direct relation between both. The cement content might be chosen since it is an indicator for more environmental (several emissions, energy) and economic (costs) effects.

Example: Transport distance of an aggregate is the actual distance from the quarry to the concrete plant, split up into t.km of truck transport and t.km of vessel transport.

Step 4 Data sources

4a Define the data sources for the indicators
Distinguish between:

- data collected within the cluster
- data required from other clusters within Eco-Serve
- data required from task 2

Example: Cluster 3 might need data on cement from clusters 1 and 2.
Data on emissions from transport can be received from task 2.
Economic data might be collected within the clusters.
A cluster panel might decide on the level of competitiveness.

Step 5 Mapping

5a Clarify the way the mapping will look like

3.5 Data

This section includes a description of data necessary for the indicators and where the data can be found. General limitations and uncertainties are also important.

Because the final goal is to be able to add contributions from different life cycle stages, it is important that conversion factors and other general data are the same through out the 4 clusters. Therefore these factors are described in this section.

3.5.1 Sources

In order so set up some practical useful indicators it is important that the data are easy to retrieve. Data already gathered for other purposes or easy to measure directly should be preferred.

Most data can be gathered from the EcoConcrete Tool and used as default values. If site specific values are available, these can used.

3.5.2 Conversion factors

Conversion factors are mainly related to energy consumption. Because emission of carbon dioxide is chosen as an indicator for all clusters factors for calculating the CO_2-emission based on the use of a specific energy source is included.

3.5.2.1 General aspects of energy calculations

When assessing energy in an LCA-context the same scale for energy has to be used including losses coming from converting fuel to electricity and poor efficiency.

Normally the term "primary energy" is used, which is the amount of energy, that has to be extracted as energy resource to meet the necessary amount of energy at the consumer. This is illustrated in Figure 3.4.

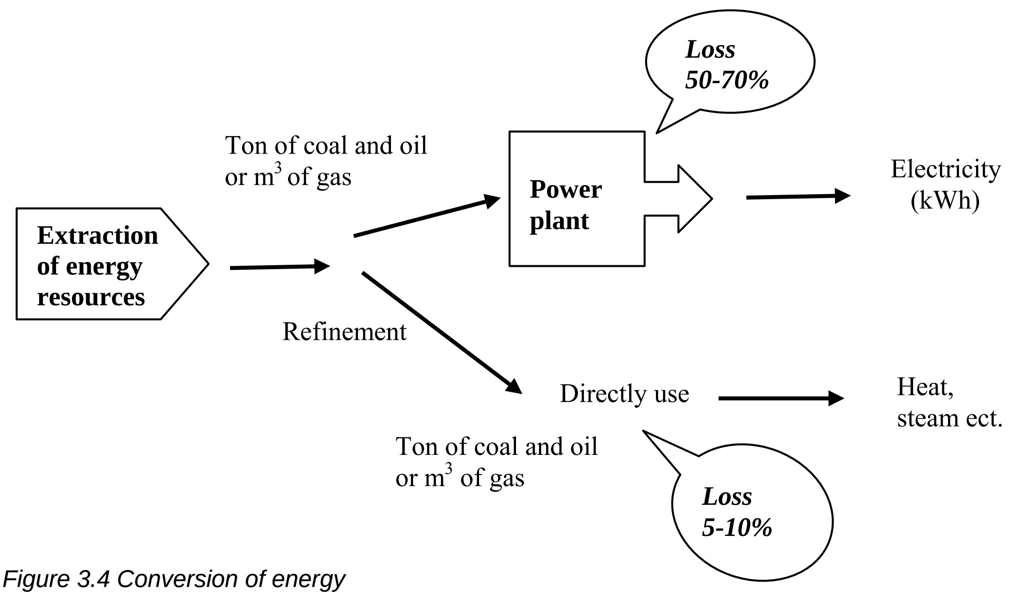


Figure 3.4 Conversion of energy

The efficiency of a power plant depends on the fuel and the technology used. In Figure 3.4 is focused on fossil fuels because of the CO_2-emissions. Besides fossil fuels, water and uranium are common energy resources.

When all consumed energy in terms of electricity, heat, oil, gas etc. are transformed to primary energy these different items can be added together.

3.5.2.2 Content of energy in materials

Energy resources and other materials have different content of energy, which can be utilised when burned. In Table 3.7 is shown a table of common materials and their energy content given as the lower calorific value. An estimate of the emitted carbon dioxide originating from fossil fuels is given as well.

Data in the table is from "Life Cycle Inventories for Packaging", 1998.

Table 3.7 Content of energy in selected materials

Material	Energy content	Emitted carbon dioxide
Heating Oil H	42.7 MJ/kg	3.76 kg/kg
Diesel Oil	42.7 MJ/kg	3.59 kg/kg
Natural gas	36.6 MJ/m^3	2.29 kg/m^3
Hard coal	29.3 MJ/kg	2.84 kg/kg
Brown Coal	8.1 MJ/kg	-
Wood	15.3 MJ/kg	0 kg/kg

Table 3.7 can be extended depending on the need from the clusters.

3.5.2.3 Data for electricity

The relevant data for electricity in this context are those, which gives the type and amount of each energy resource used to produce 1 kWh for the consumer. Also the amount of CO_2 emitted by using 1 kWh is relevant.

Such data are normally not included in ordinary statistics. The data are based on tables from "Life Cycle Inventories for Packaging", 1998.

Table 3.8 : Energy consumed and CO_2-emissions for producing 1 kWh(3,6 MJ)

	Raw material	**Energy**	**CO_2-emitted**
Oil	0,275 kg	9,68 MJ	0,88 kg
Gas	0,241 Nm3	6,93 MJ	0,77 kg
Nuclear energy	0,029 gram	9,64 MJ	0 kg
Hard Coal	0,613 kg	9,1 MJ	0,98 kg
Brown Coal	1,48 kg	10,9 MJ	1,35 kg
Hydro	4,7 m^3	1,1 MJ	0 kg

The way of producing electricity varies through out Europe. This is shown in Table 3.9. The data is from 2002 based on information from IEA and other sources.

Table 3.9 Energy resources used for production of electricity and the average CO_2 emissions

	Percent of resources used for production of electricity						
	coal	oil	gas	hydro	Nu-clear	Re-newa-bles	Kg CO_2 emitted per kWh
Austria	9	5	14	68	0	3	0,244
Belgium	15	1	23	1	59	2	0,326
Cyprus 1)	68	18	8	4	0	2	0,887
Czech Republic	75	0	0	14	11	1	0,735
Denmark	49	12	22	0	0	17	0,753
Estonia	91	0	9	0	0	0	0,959
Finland	23	1	15	18	31	12	0,352
France	5	2	2	14	77	1	0,077
Germany	51	1	10	4	30	4	0,590
Greece	68	18	8	4	0	2	0,887
Hungary	25	24	12	0	39	0	0,549
Ireland	35	29	33	3	0	2	0,841
Italy	11	34	33	18	0	3	0,667
Latvia	0	4	28	67	0	0	0,256
Lithuania	0	6	11	5	78	0	0,136
Luxembourg	0	0	55	28	0	17	0,424
Malta 2)	32	11	8	18	27	4	0,466
Poland	91	1	2	6	0	1	0,916
Portugal	28	20	15	31	0	4	0,577
Slovakia	30	0	0	16	54	0	0,294
Slovenia	35	0	0	27	37	0	0,345
Spain	32	11	8	18	27	4	0,466
Sweden	2	2	0	51	43	2	0,036
The Netherlands	25	8	57	0	4	5	0,760
United Kingdom	31	1	42	1	24	2	0,633
1) Data for Cyprus is calculated with data from Greece 2) Data for Malta is calculated with data for Spain							

1

As can be seen from Table 3.9, there is a great difference between the energy resources used in the EU-25 countries. This can also be seen in the average amount of emitted CO_2 per kWh. When taking the annual production into account the average amount of emitted carbon dioxide is 0.475 kg per kWh.

When the amount of consumed energy and the geographical area is known, the amount of carbon dioxide can be calculated directly.

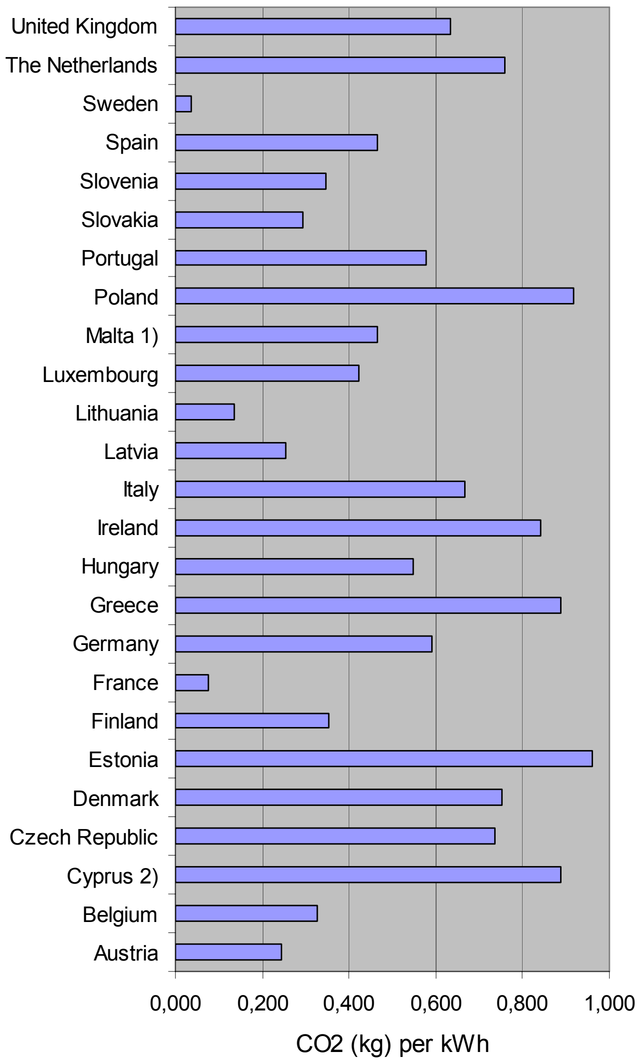


Figure 3.5: Emitted carbon dioxide in average per consumed kWh

3.5.2.4 Data for thermal energy sources

When using oil, gas or other energy resources, these are normally measured in amount of kg, m^3 or anther weight or volume unit. In order to estimate the amount of emitted carbon dioxide from these processes the following data can be useful.

By spending for instance 1 kg heating oil it is necessary to extract 1.13 kg. Combusting 1 kg of heating oil in produces 42,7 MJ (see Table 3.10). If the efficiency is 90%, then 38 MJ of thermal energy can be used. Combustion of 1.13 kg oil causes the formation of 3,76 kg carbon dioxide.

In Table 3.10 data for common energy resources are shown. The content of energy is based upon the lower calorific value. Efficiency means the loss at the combustion site; - here is chosen 90%, but it may be lower.

Wood is included in Table 3.10. Because wood is a renewable resource, it can be questioned whether or not it's contribution should be included in the amount of carbon dioxide emissions. In general, the use of renewable resources is not included.

Table 3.10 Energy content and emission of carbon dioxide for thermal energy production.

Energy source	Primary energy resource	Energy content	Available energy 90% eff.	Carbon dioxide pr kg spent source	Carbon dioxide pr. used MJ (90% eff.)
Heating oil	1.13 kg	42,7 MJ	38 MJ	3,76 kg	98.9 g/MJ
Natural gas	1.12 Nm^3	36.6 MJ	33 MJ	2.29 kg	69,5 g/MJ
Coal	1.66 kg	29,3 MJ	26 MJ	2.84 kg	108 g/MJ
Wood	*1.05 kg*	*15,3 MJ*	*14 MJ*	*2.99 kg*	*217 g/MJ*
Petrol	1.19 kg	42,8 MJ	38 MJ	3.98 kg	105 g/MJ
Diesel	1.09 kg	42.7 MJ	38 MJ	3.59 kg	94.5 g/MJ

3.5.2.5 Data for transportation

The consumption of fuel and the emissions related to transportation may be relevant when comparing transport with production processes.

In the general LCA-methodology, the fuel consumption is based upon the type of transportation (sea, road or rail) the amount transported and the distance. When knowing the amount and type of consumed fuel this can be converted to amount of CO_2 emitted.

In Table 3.11is given the conversion factor for calculating the consumption of fuel and the emission of carbon dioxide. When using power (electricity) the average for Europe (UCPTE) is used. Emissions based on combustion of oil are based on the figures from Table 3.10.

Table 3.11Energy consumption for transportation and emission of carbon dioxide

	Assumed efficiency	Energy resource				gram CO2 per ton x km
		Heating oil [kg]	Diesel [kg]	Petrol [kg]	Power [kWh]	
Trans oceanic freighter	60%	0,0022				8
Inland waterways freighter	70%		0,011			39
Private car, western Europe			0,012	0,051		246
Delivery van <3,5 ton	50%		0,0263	0,111		536
Lorry, 16 tons	50%		0,0635			228
Lorry, 28 tons	50%		0,0423			152
Lorry 40 tons	50%		0,0259			93
Rail, electric			0,0011		0,058	29
Rail, electric and diesel			0,0033		0,042	30

4. Cluster 1, Use of waste as secondary fuels and raw materials for cement production

4.1 Introduction

Cluster 1 deals with the use of alternative materials in cement production as fuels or raw materials and the resulting environmental behaviour of the produced cement.

In figure 4.1 are shown how the activities in Cluster 1 are related to the activities in the other clusters and how relationships are established in a life cycle perspective.

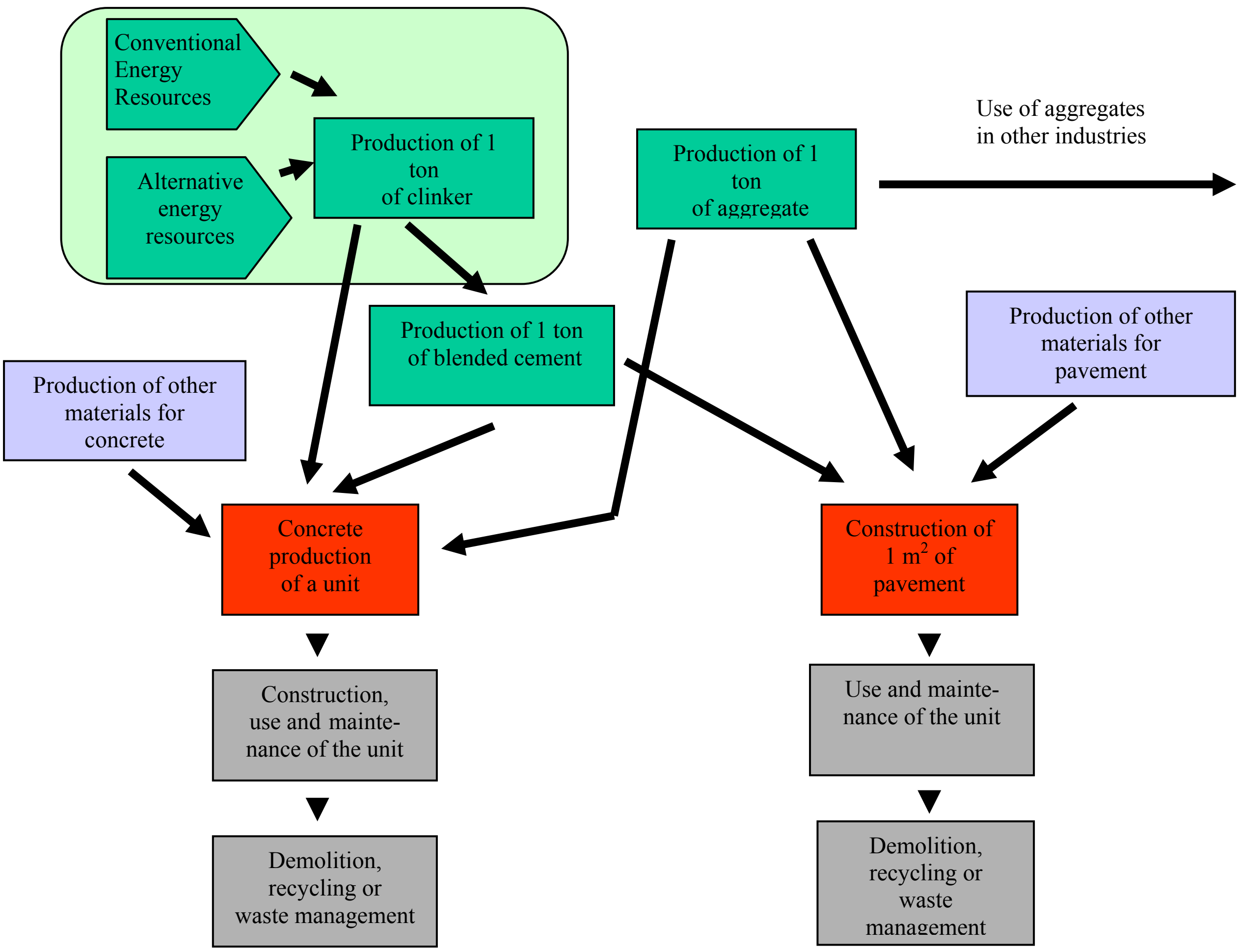


Figure 4.1 Activities in Cluster 1 seen in a life cycle perspective.

Changes in clinker production may affect almost all other activities. It needs to be considered whenever concrete is corrected. The later stages of the life cycle for concrete will also be important.

4.2 Goal and scope

4.2.1 The central question

The central question reflects the goal for cluster 1 and can be expressed as:

> *Do the use of alternative materials or alternative energy sources compared to those used conventionally cause any changes on the impact of the products whole life cycle, when focused on environment, working environment or productivity?*

The central question addresses activities in cluster 1 as well as activities in the other clusters and the last part of the products life cycles as shown in Figure 4.1

4.2.2 The functional unit

The functional unit is not defined within the activities of cluster 1. The output from cluster 1, a certain amount of cement, characterised by the content of conventional and alternative raw materials as well as impurities from alternative and conventional fuels, serve as inputs to manufacturing of blended cement and concrete.

Instead of defining a functional unit here is defined a material unit. It is proposed to be 1 ton of cement characterised by the substances it is made of.

4.2.3 Technology options

The following types of alternative materials will be studied:

- tyres
- waste oil, other organics (oil mud, organic distillation residues)
- fractions from industrial and commercial waste (pulp, paper and cardboard, plastics, packaging, waste from textile industry, etc.)
- biomass (meat and bone meal, animal fat etc)

4.3 Life Cycle definition

4.3.1 The life cycle stages

The life cycles of concrete mortar with ‘traditional’ cement and cement produced by secondary fuels and alternative raw materials do not differ very much. They have the same life cycle stages; only some cement-specific processes differ. Therefore only the processes that differ, are looked at in this analysis. These processes in the life cycle of concrete mortar are the following:

(I) Raw material extraction for cement: extraction + transport of raw materials versus acquisition of alternative raw materials;
Extraction + transport of fossil fuels versus secondary fuels

It is estimated that transport of alternative materials is approximately the same as transport of raw materials and fossil fuels. The differences are neglected in this analysis.

(II) Production of cement: clinker production
(III) Construction: no differences
(IV) Use/maintenance: leaching of concrete
(V) Demolition / recycling / disposal: leaching of concrete that is disposed or recycled as granulate

4.3.2 Important life cycle stages

The important issues in the life cycle stages (as far as the above-mentioned processes are involved), are indicated in the Table 4.1, where it is differentiated into the three Eco-Serve topics for external environment, working environment and productivity/competitiveness/quality.

Table 4.1 Important life cycle stages in Cluster 1.

Influence on	**external environment**	**working environment**	**productivity / competitiveness / quality**
Life cycle stage			
Raw material acquisition	Resource depletion Alternative materials versus waste products Alternative fuels versus conventional	Handling and processing of alternative materials (e.g. dust)	Potential additional costs of handling and processing
Cement clinker production	Emissions (CO_2, NOx and others) For conventional energy resource depletion	Handling and processing of alternative materials Working environment (dust, mercury)	Material/fuel costs or savings Potential additional costs of handling and processing Potential additional costs for cement quality requirements
Construction activities	No remarks	Cr (VI) bleeding	Initial material costs (if concrete price differs) Potential extra costs for safety measures (regarding leaching risks)
Use & Maintenance	Leaching	none	Durability costs (if life time concrete mortar differs)
Demolition and waste treatment (disposal / reuse)	Leaching	Dust emissions at demolition	Recyclability? (if different)

Regarding the external environment and the first life cycle stage, raw material acquisition both resources for materials and energy has to be considered. It depends on the traditional waste treatment and other alternatives. Alternatives for waste treatment might be more effective than the use for cement production. It could also be the case that a secondary material has such a high price that it is not regarded as a waste material anymore. This means that the production should be allocated to the secondary material. This allocated environmental impact might be higher than the impact of traditional raw materials, leading to e.g. higher resource depletion or higher emissions.

Regarding the external environment and the clinker production, the amount of energy required per ton clinker will in most cases remain the same. The benefits from alternative materials should be the resource depletion and (sometimes) emissions.

4.4 Indicators

4.4.1 Important Influences

- Environmental indicators:
  - The energy demand in MJ/t is considered to be similar for traditional cement versus cement produced using alternative materials. Energy is therefore not interesting as environmental indicator.
  - Emissions to air at cement production are no investigation topic for cluster 1 (regarding the main goals). Emissions are considered a side-effect, that should be checked but is not a goal in itself.
- Working environment indicators: covered by occupational requirements and therefore not subject of study in cluster 1.
- Economical indicators:
  - Costs (savings) in cement production are very location specific and therefore not suitable as general indicator in cluster 1.
  - Concrete price is considered to be similar for all cement types.
  - Potential additional costs in the concrete life cycle due to risks (leaching, durability, and recyclability) are not known and neglected in cluster 1.

4.4.2 Arguments for potential indicators

- *Resource depletion*
  Relevant in the clinker production, it is represented by fossil fuel amount and therefore best expressed in terms of fossil fuel replacement. Fossil fuel ‘amount’ expressed by calorific value could be a useful unit. Calorific values from various alternative materials already known.
- *Leaching*
  A simplified procedure to use in daily QC (quality control) will result in indicators for potential leaching problems during the whole life cycle. Existing data (database) will serve as benchmark.

4.4.3 Selected indicators

The selected indicators are listed in Table 4.2.

Table 4.2 Selected indicators for cluster 1.

Environment	Emissions from production of clinker. Leaching during use, demolition, recycling and waste treatment Amount of fossil fuel replacement.
Working environment	None
Productivity / competitiveness / quality	None

Comment to Table 4.2:

The emissions from clinker production to be used as indicators have to be specified. It needs to be expressed in terms of specific substances. Data on emissions for specific types of waste as for instance discarded tyres, waste oil, plastics and other relevant alternatives will be gathered.

In the collection of data for emissions focus has been on air borne emissions. Also substances relevant for leaching should be specified. It is expected that the main focus will be on heavy metals, and here the most important should be pointed out. Other substances may also be considered.

5. Cluster 2, Blended Cement

5.1 Introduction

In cluster 2 the activities are focused on energy consumption and emission of carbon dioxide related to the production of blended cement.

In Figure 5.1 are shown how the activities in cluster 2 are related to the activities in all other clusters and how the relationships are seen in a life cycle perspective.

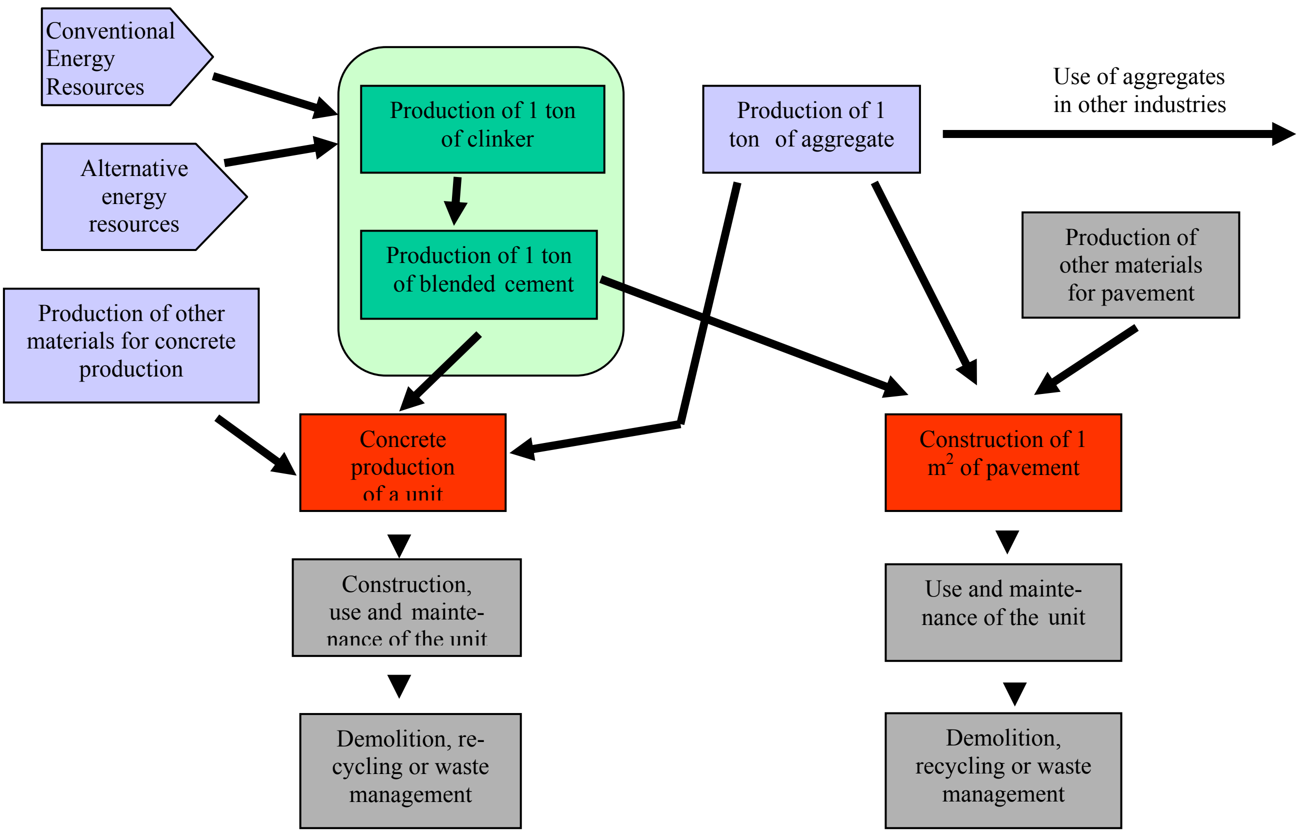


Figure 5.1 Activities in Cluster 2 seen in a life cycle perspective

As can be seen in Figure 5.1 changes in production of clinker and blended cement may cause changes in the activities related to concrete production and pavement constructionWhile changes in the cement this may cause changes in the need/use of specific aggregates.

5.2 Goal and scope

5.2.1 Central question

Cluster 2 is dealing with production of clinker and blended cement. In reducing the environmental impact focus is on reduction of energy, and here a reduced clinker content leads less consumption of energy. The central question for Cluster 2 is therefore:

> *Which compositions of blended cements (reduced clinker content) are feasible in Europe within and beyond the limits of EN 197-1?*

The types of blended cement (CEMII-V) are defined as in the strength classes 32.5 N/R, 42.5 N/R and 52.5 N/R.

Durability is another issue of interest for Cluster 2. If durability and lifetime of a construction can be increased, the environmental impact and the costs spent on production of the construction will decrease when calculated per year.

Cluster 2 are also focusing on the working environment as well as productivity, competitiveness and quality. No specific questions have been formulated. The goal for the working environment is not to introduce any disadvantages while resource consumption is optimised. Optimising on resource consumption the cost per ton produced blended cement will decrease.

There is a great difference within Europe regarding the use of cement and blended cement, and the different types of materials blended with cement. This primarily can be explained by regional available resources such as blast furnace slag in areas with steel production factories. In other areas dominated by incineration of coal for electricity production fly ash is commonly used. An important parameter as well is the availability of limestone.

5.2.2 Functional unit

The functional unit related to a life cycle perspective in the building industry is not 1 ton of blended cement. It is a unit that represents a service that can be defined.

In this case the functional unit is defined as 1 ton of concrete, where the units function, strength, durability etc. are defined.

Blended cement being a material input to the concrete production, indicators for blended cement are therefore based on the material unit 1 tonne of blended cement, where the composition and properties of the cement is defined.

The important point is that different types of blended cement can bee used for production of concrete with exactly the same properties can be compared.

5.2.3 Technology options

The technology options studied in the cluster are primarily materials that can partly substitute clinker content in blended cement.

Materials are considered are :

- primary materials: limestone, natural pozzolans, …
- secondary materials: fly ash, slag, silica fume, …

In addition possibilities for minimising energy consumption is also studied.

This section has to be completed when Cluster 2 has more specific proposals.

5.3 Life cycle definition

5.3.1 The life cycle stages

Production of blended cement is part of a life cycle where the cradle can be defined as extraction of raw materials and the grave as demolition and waste management of a building.

The life cycle stages in general can be defined as in Figure 5.1. where it is shown that the focus of cluster 2 is the part of the life cycle that consists of clinker production and manufacturing of blended cement. These two stages are shown with a grey colour. The rest of the life cycle, which may be affected by changes in these two stages, are shown with in white.

Stage 1 in the life cycle includes extraction of raw materials for clinker production, e.g. mining of limestone, other materials as well as resources for energy consumption. The production of aggregates in this context is included in this stage.

Stage 2 includes the manufacturing of blended cement, - splitted into two parts. First clinker production and second blending the clinkers with other materials. As shown in figure 1, in some situations clinkers are used directly in stage 3. Transportation of raw materials from stage 1 to stage 2 is included in stage 2.

Stage 3 covers the manufacturing of a unit of a given concrete product. Besides blended cement or not-blended cement, aggregates are used as well as other materials and admixtures. Transportation of the materials to stage 3 (from stage 1 and 2) are included in stage 3.

Stage 4 covers the construction activities. Besides the concrete product (e.g. a roof panel) energy consumption is included. The amount of ancillary materials is included, but not the manufacturing of these. The focus is on changes related to changes in the type of cement. Transportation of materials to stage 4 is included.

Stage 5 includes use and maintenance of the construction. Influences of the quality and other properties of the construction with respect to changes in the type of cement are included. This can be relevant if durability or maintenance is affected. Transportation of materials to stage 5 is included.

Stage 6 covers demolition and handling of dismantled material. It is important to focus on changes in the amount of recyclable material as well as the required proper handling of waste. If changes in the cement / blended cement causes any changes in the fraction of recyclable material as well as the necessary treatment this is included. Also included are any changes in the requirement for waste disposal related to changes in the cement. Transportation related to activities in stage 6 is included.

5.3.2 Important life cycle stages

Effects caused by changes in the production of clinker and blended cement are shown in Table 5.1. The table includes changes in the environment which respect to changes in emissions to air, potential changes in leakage to water and soil as well as changes in the type and amounts of waste and recyclable materials. Also are included potential changes in the working environment regarding noise and dust. Parameters related to productivity, competitiveness and quality are also included.

Table 5.1: Effects in the life cycle

Influence on	External environment	Working environment	Productivity / competitiveness / quality
Life cycle stage	Cause	Cause	Cause
1. Raw material acquisition	Extraction of limestone (decreasing) if scarcity. Extraction of alternative materials. Extraction of aggregates if scarcity.	Dust and noise from extraction processes.	Material costs
2. Production of clinker and blended cement	*Reduction of raw materials for clinker production.* *Use of fly ash and blast furnace slag.* *Reduction of emissions from decreased energy consumption (including energy resources).* *Reduction of CO_2-emissions from calcination*	*Handling of e.g. fly ash? (dust)* *Handling of clinker (dust)* *Noise from grinding clinker*	*Production costs* *Cement class (quality)*
3. Concrete production	*Consumption of energy*	*Risk factors regarding*	*Quality ??*

	(including energy resources) *Use of ancillary materials.*	*handling of cement and concrete, corrosion damages.*	
4. Construction activities	*Consumption of energy (including energy resources)* *Use of ancillary materials.*	*Risk factors regarding use of ancillary materials.*	
5. Use & Maintenance	*Consumption of energy (including energy resources)* *Use of materials.*	*Risk factors regarding use of materials.*	*Durability*
6. Demolition and waste treatment (disposal / reuse)	*Consumption of energy (including energy resources)* *Requirements for waste disposal.* *Amount of recyclable materials and what this can substitute*	*Dust and noise from demolition and crushing / grinding.*	*Fraction of recyclable materials and quality of these.*

The main focus will be on stage 2 and changes to other stages caused by changes in stage 2.

5.4 Indicators

5.4.1 Important influences

Since the main purpose for Cluster 2 is to focus on clinker content is important to show indicators that can illustrate the environmental impact, working environment as well as economic aspects. It is important to focus on simple and measurable indicators and to show changes in the whole life cycle caused by changes in stage 2.

Former LCA studies have shown that for the external environment, clinker content is the dominant parameter as it influences mainly CO_2 and energy demand.

For the economic part, durability and product costs are an important parameter.

Leaching is not investigated since it is already topic of cluster 1.

5.4.2 Proposed indicators

The proposed indicators for Cluster 2 are listed in Table 5.2 .

Table 5.2 Indicators for Cluster 2

Indicator	Unit	Effect
Environment		
1)Clinker content	kg per ton blended cement	Gives information regarding the CO_2 emissions from calcination
2) Use other materials, e.g. fly ash, blast furnace slag	kg per ton blended cement	Makes it possible to evaluate the use of secondary materials
3) Energy consumption and type of energy resource	kg oil per ton blended cement or kWh per ton blended cement	Makes it possible to calculate emissions
4) Transportation	Amount of tons transported a specific distance in km by truck, ship etc.	Calculation of the consumption of energy and the related emissions
Working Environment		
5) Noise from grinding	Estimated man hours per ton blended cement with more than 80 dB(A).	Evaluation of potential hearing loss
6) Dust from fly ash, clinker and cement	Estimated man hours per ton blended cement with more than 10 mg dust per m^3	Evaluation of potential lung damage.
Productivity / competitiveness / quality		
7) Production cost	Man-hours per ton blended cement	Evaluation of the variable costs (cost for energy and materials might be added)
8) Quality	Cement class	Defines the quality
9) Durability	Measured in life time (years) of the construction.	Defines durability

Cluster 2 has chosen to focus only the clinker content, which has a great impact on the emissions of carbon dioxide.

5.5 Data Sources

Regarding the clinker content Cluster 2 has gathered some data to illustrate the reduction on carbon dioxide when part of the clinker content is substituted by other materials (Müller C and Siebel E, 2004). The result are illustrated in the following figures.

Figure 5.2:CO_2 reduction from the production of blended cements

Substitution of clinker by granulated slag for a CEM II/B-S 32.5 with 35 % granulated slag

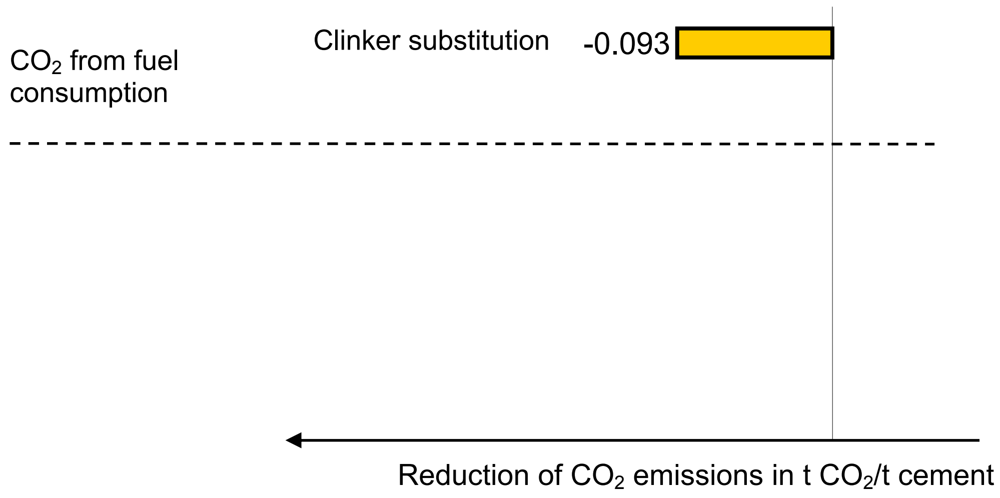


Figure 5.3: CO_2 reduction from the production of blended cements

Substitution of clinker by granulated slag for a CEM II/B-S 32.5 with 35 % granulated slag

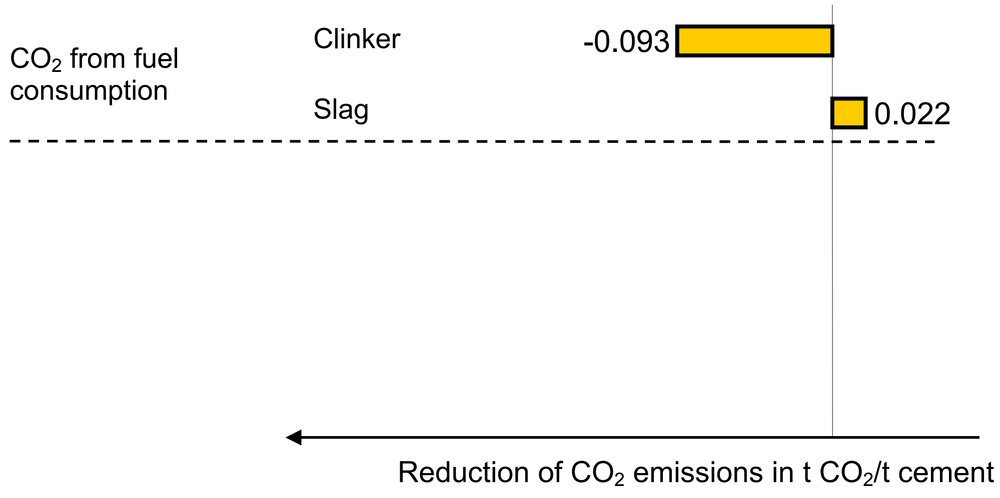


Figure 5.4: CO_2 reduction from the production of blended cements
Substitution of clinker by granulated slag for a CEM II/B-S 32.5 with 35 % granulated slag

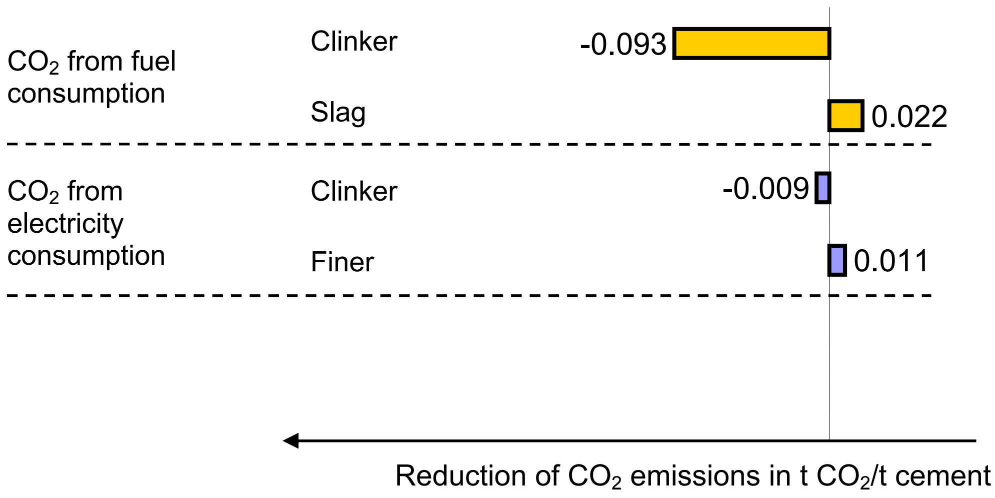
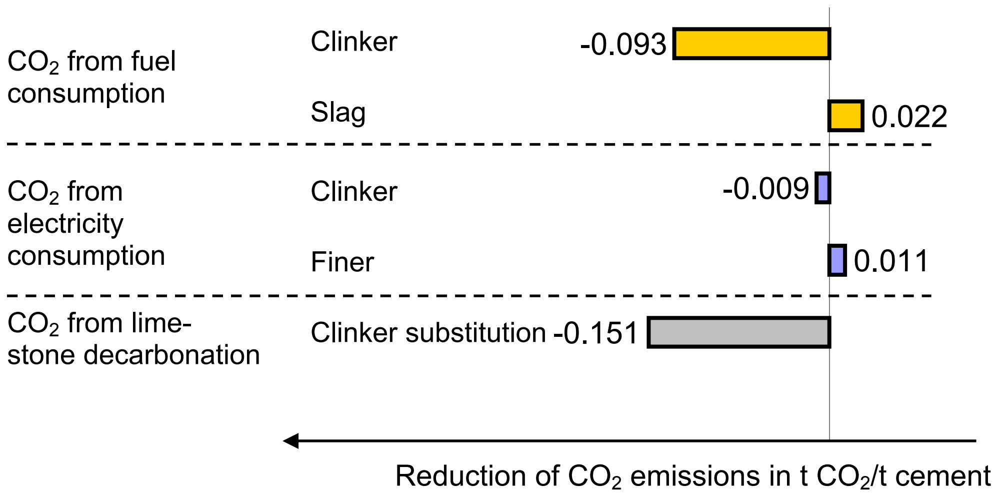


Figure 5.5: CO_2 reduction from the production of blended cements
Substitution of clinker by granulated slag for a CEM II/B-S 32.5 with 35 % granulated slag



In figure 5.6 is shown the relationship between the content clinker, the consumption of energy and the emission of carbon dioxide.

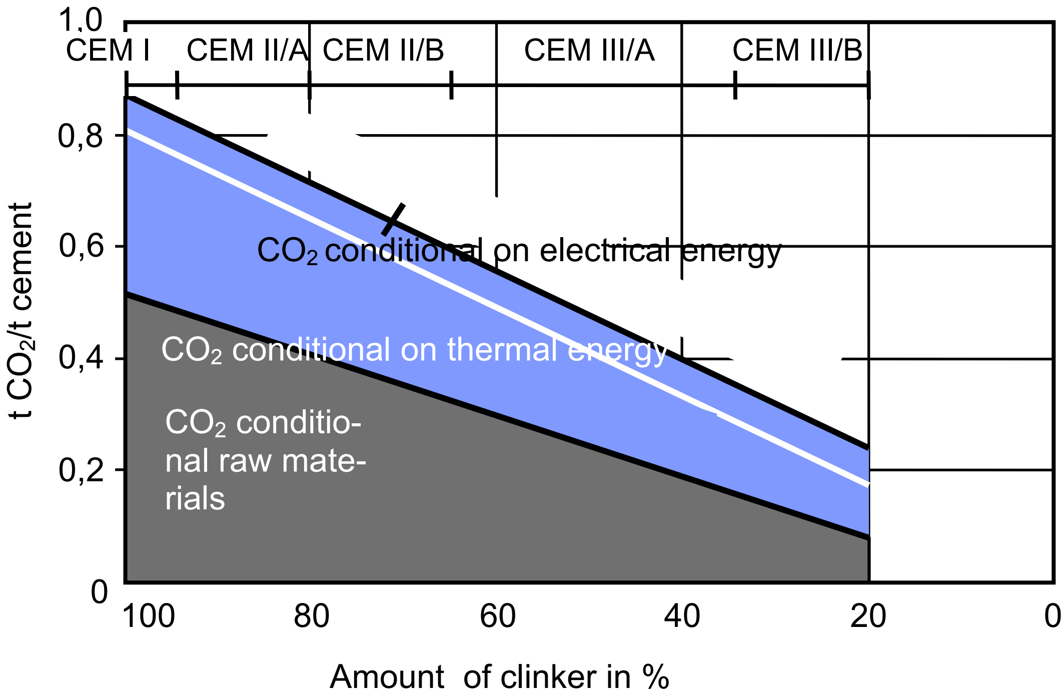
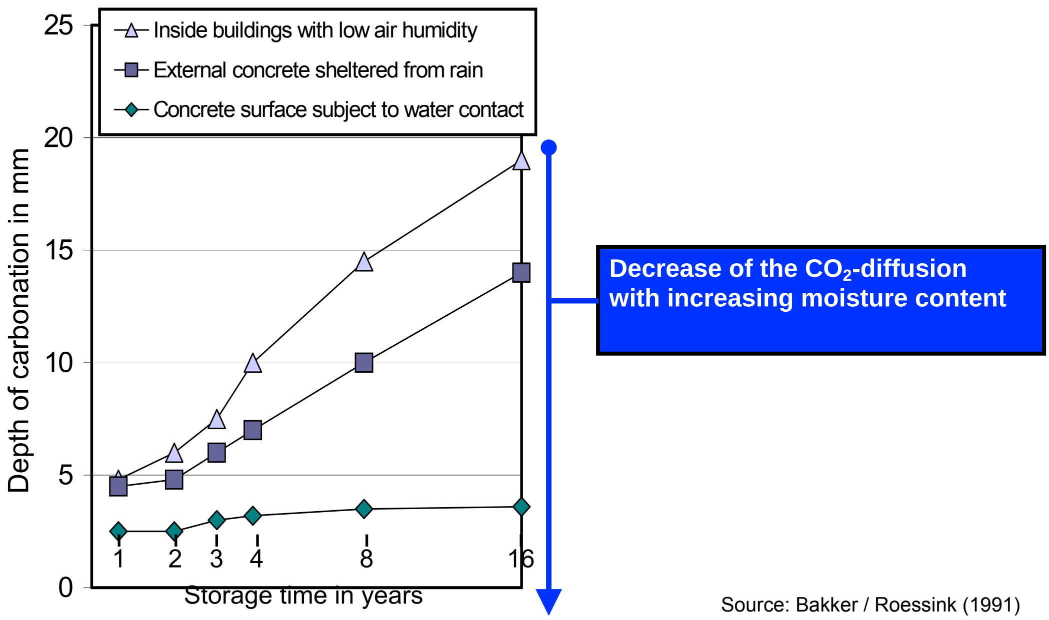


Figure 5.6: Emission of carbon dioxide as a function of the clinker content

Cluster 2 has as well looked into data for carbonation of concrete. An example of this is shown in figure 5.7.

Figure 5.7: Depth of carbonation – Influence of the environment



Data from Cluster 1

From the cluster the following data can be used:

1. Amount of raw materials for production of 1 ton of blended cement
2. Amount of energy (kg fossile fuel (coal or oil) kWh of electricity)
3. Estimation of transport distance (in km), amount (in kg) and method (truck, ship, train)
4. Estimation of noise level close to grinding operations and other relevant facilities
5. Handling of fly ash, clinker and cement, - wet or dry processes, open or encapsulated processes
6. Man hours per ton of blended cement produced.

Data from other Clusters

I. Data regarding aggregates and concrete production will be transferred by Task 2 from Cluster 3.
II. Data regarding leaching will be transferred by Task 2 from Cluster 1.
III. Data regarding durability of the concrete product will be transferred from cluster 3.

Data retrieved from chapter 3

A. Estimation of CO_2 emission from the calcination based on consumption of limestone
B. Estimation on CO_2 emission from consumption of energy for the processes
C. Estimation on CO_2 emission from transportation

6. Cluster 3, Aggregates

The activities in Cluster 3 cover both aggregates and concrete. Here they are presented separately as they cover different stages in the life cycle. Concrete is described in chapter 7.

6.1 Introduction

The overall objective of Cluster 3 is to contribute to reduce the environmental impact of aggregate production making them more cost-effective while improving or at least maintain the technical performance.

Figure 6.1 illustrates how activities related to aggregates are related to other activities in other clusters and how the relationships are seen in a life cycle perspective.

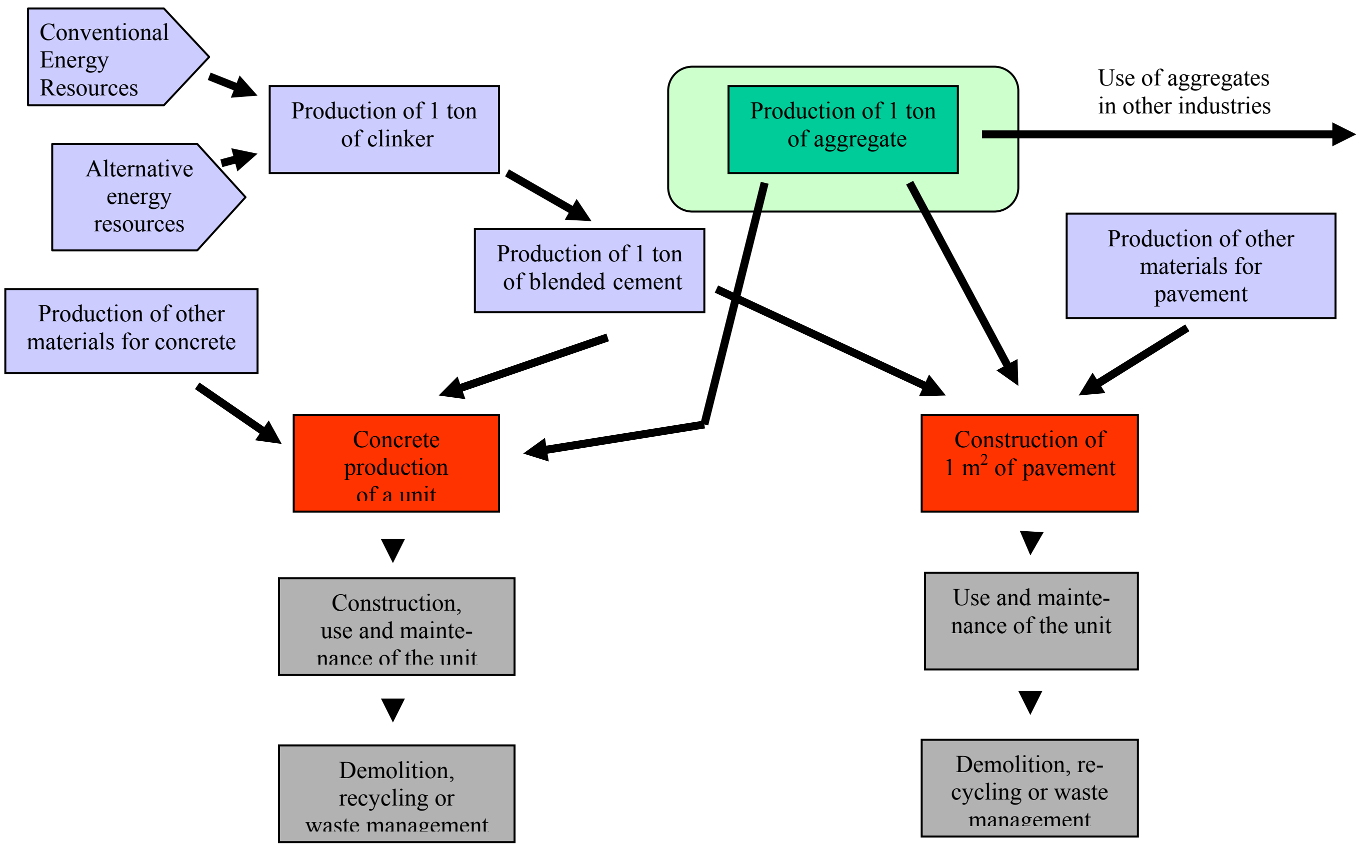


Figure 6.1 Activities regarding aggregates in a life cycle perspective

As can be seen in Figure 6.1 changes in the production of aggregates may have an impact on the two functional units, - concrete production (Cluster 3) and construction of pavement (Cluster 4). Changes in activities regarding cement and blended cement may also affect the need/use of specific aggregates.

6.2 Goal and scope

6.2.1 The central question

The central questions for aggregate production are:

1. *What are the most essential environmental issues?*
2. *How do new technologies affect the environmental performance?*

Question 1 is partly answered by the selection of the most important indicators and therefore partly answered by the cluster.

Question 2 will be answered when using the indicators and data from the baseline study and the description of new technologies.

6.2.2 Functional unit

In the case of aggregates it is not relevant to define a functional unit, as aggregates are used as inputs in the production of concrete, in the construction of pavements and for a number of other purposes.

Therefore the material unit is 1 tonne of aggregates with defined characteristics (origin, type, size etc.).

6.2.3 Technology options

In order to benchmark different aggregate manufactures all over Europe the project group of Cluster 3 suggests the following options to be mapped:

- manufactured sand
- natural aggregate
- sand (fine aggregate).
- coarse aggregate
- aggregates for concrete
- aggregates for bituminous mixtures and surface treatment for roads, airfields and other trafficked areas
- aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction

6.3 Life cycle definition

6.3.1 The life cycle stages

The life cycle stages for aggregate production are shown in Figure 6.2. where the different ways of using aggregates are outlined.

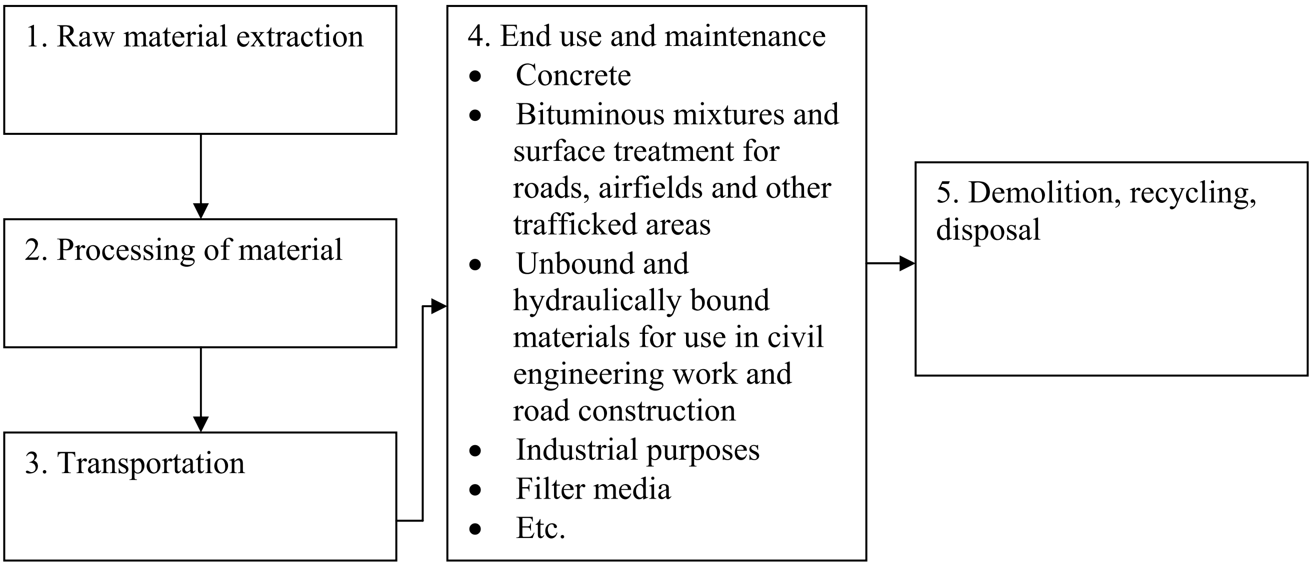


Figure 6.2 Life cycle stages for aggregates

6.3.2 Important life cycle stages

Manufacturing of aggregates naturally focuses on the winning of raw materials, crushing or other treatment and transportation.

Land use in another important issue and very difficult to assess, because of lack of accepted methods. Production waste and the possibilities of reuse waste is another important environmental parameter. With respect to life cycle stages in Figure 6.2 the main issues are indicated in Table 6.1.

Table 6.1 Important issues in the aggregate production

	Cause
Environment	Production waste in aggregate production Land use Transport distances
Working environment	Dust Noise
Productivity /competitiveness /quality	Costs of spilling material Quality

6.4 Indicators

6.4.1 Potential indicators

Cluster 3 has chosen to work with indicators in the four categories:

- Energy
- Use of resources
- External environment
- Working environment

Cluster 3 has considered a number of indicators, that might be relevant. These indicators are shown in Table 6.2. Some of the indicators are measurable and others are not, - either because no accepted method is available or because data will be confidential.

Table 6.2: Relevant indicators for aggregate production

Indicators	**Measure**	**Comments**
ENERGY		
Transport constraints	Average transport distance from source to customers and % of transport by road, rail and water	This indicator would only be relevant to the aggregates industry.
Energy efficiency	$\sum$ energy carriers in MJ per functional unit	The lime industry expressed particular confidentiality concern because energy costs represent 40% of the total cost
USE OF RESOURCES		
Water demand	$\sum$ of net raw water consumption (= m^3) per functional unit (1 ton product)	Suggestions are to be submitted regarding the measurement
Land demand	total of land area put into use for mineral extraction during the year n	
Land management	total surface land area returned to beneficial use / new surface land area put into use for mineral	
EXTERNAL ENVIRONMENT		
Use of dangerous substances	Rate of classified dangerous substances having potential risk to environment and/or human health used in the mineral process per functional unit (%)	
Environmental incidents	Number (and kind) of reportable environmental incidents.	
Communication to the Community	Does the company have a system for registration and follow-up complaints (YES / NO)	

WORKING ENVIRONMENT		
Health & safety of employees	Number of working hours lost per year as a result of accidents/ total of hours worked	
	Number of fatalities per year	
	Number of hours of training in Health & Safety / total number of hours worked	

6.4.2 Selection of indicators

Selected indicators for aggregates by Cluster 3 are shown in Table 6.3.

Table 6.3 Indicators for aggregates

Influence on	**External environment**	**Energy use**	**Consumption of resources**	**Working environment**
Life cycle stage	Cause	Cause	Cause	Cause
Raw materials acquisition		Sum of energy consumption in MJ per functional unit	Land use ratio for year N 1)	Percentage work hours lost per year due to accidents or work related decease
Aggregate production			Surplus fines that need depositing – functional units	
Aggregate transport and delivery		Transport scheme from quarry to customer by road, rail, or water 2)		

1) Land use ratio: Land area taken into use for aggregate quarrying divided by land area returned to beneficial end-use
2) Transport scheme: Average distance and percentage of functional unit by road, rail and water respectively.

6.4.3 Other indicators

The following indicators will be included in the discussion in the baseline report on aggregates at member state level

Indicators	**Measure**	**Comments**
Sustainable access to resources	Number of extraction permits granted / number of extraction permits inquired	
Land granted for minerals extraction	Land area permitted for mineral extraction / National area	It was suggested to combine this with the indicator ‘land demand’
Material demand	Material demand per capita	Shall be based on finished products
Contribution to GDP	Turnover / GDP (MSs, EU) Turnover should be given as “ex-work”, i.e. without costs of transport to customers.	Extent if possible to indirect employment
Trade balance	Mined/extracted products within the EU vs. Mined/extracted products imported from outside	

	(tonnes)	
Sensitivity	Number of Natura 2000 sites in which a company operates extraction activities (or which are adjacent to extraction sites)	This indicator will only apply to MS Clarification on REMSA (wetland) sites will be submitted
External co-operation in sustainable development of the non-energy extractive industry	Existence of external co-operation programmes covering sustainable development of the non-energy extractive industry	

7. Cluster 3, Concrete Production

Activities in Cluster 3 cover both aggregates and concrete production. Here activities are presented separately as they cover different stages in the life cycle. Aggregates are described in chapter 6.

7.1 Introduction

The overall objective of Cluster 3 is to contribute to reduce the environmental impact of concrete production making it more cost-effective while improving or at least maintaining technical performance.

Figure 7.1 shows how activities related to concrete production are related to activities in other clusters and how the relationships are in a life cycle perspective.

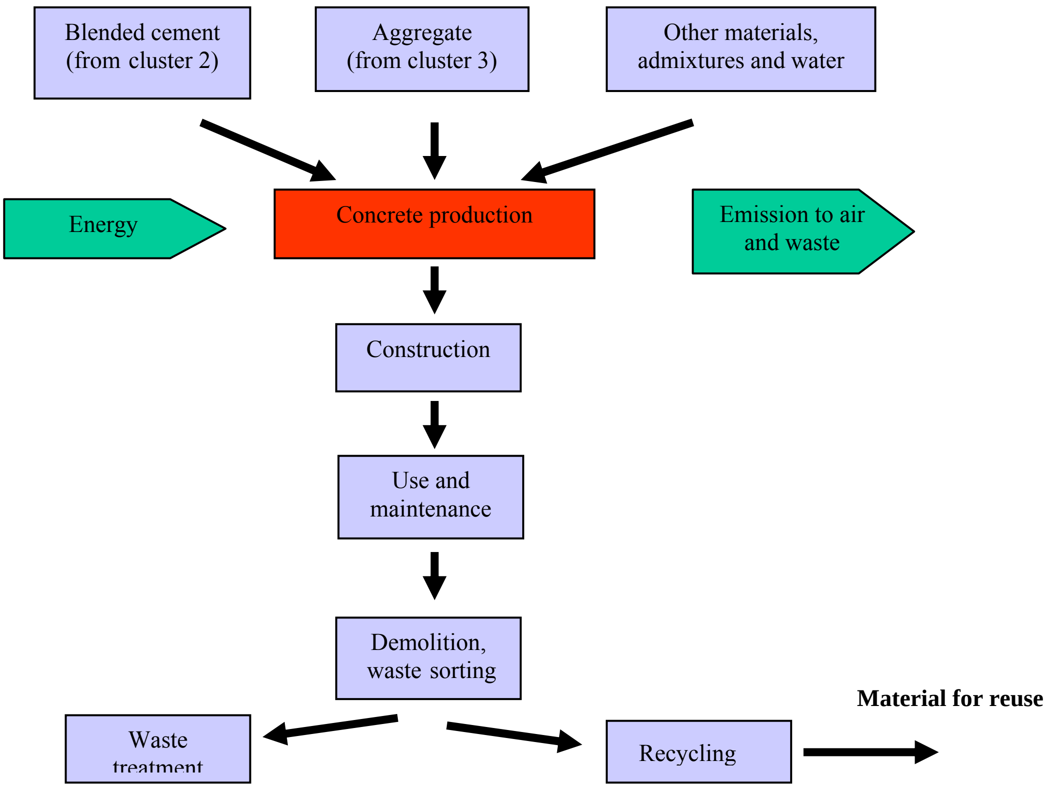


Figure 7.1 Activities regarding concrete seen in a life cycle perspective

From figure 7.1 it appears that activities in Cluster 3 regarding concrete do not affect the work done in cluster 4, pavement, - but do include Cluster 1 and 2. Activities in cluster 4, pavement may be affected by changes in blended cement and aggregates, - see chapter 8.

Activities in Cluster 1, 2 and 3 will affect later stages in the life cycle such as maintenance, demolition, waste treatment and recycling.

7.2 Goal and scope

7.2.1 The central question

The central questions for the concrete production are:

1. *What are the most essential environmental issues?*

2. *How do new technologies affect the environmental performance?*

Question 1 is partly answered by the selection of the most important indicators and therefore partly answered by the cluster (see section 7.2)

Question 2 will be answered when using the indicators and data from the baseline study and the description of new technologies.

7.2.2 Functional unit

Production of a concrete unit, for instance a panel, a part of a bridge or other elements of construction is defined as the functional unit.

Therefore this specific product has to bee defined carefully in order to describe the function and service, that the product provides. Only products that provides the same function and service can bee compared.

For a concrete panel (or other concrete products) the weight, volume and/or area together with information on exposure class, strength class and W/c-ratio will be part of the definition of the functional unit.

Besides this the durability, - or the lifetime of the product is essential.

Other properties may be relevant. If the appearance of the surface is important or maintenance is relevant, parameters for this have to be defined.

7.2.3 Technology options

Cluster 3 has suggested the following mix designs:

<u>Mix Design 1. (passive environment)</u>

Exposure class:	X0, XC1
Strength class:	20 MPa
W/c-ratio:	0,60-0,70

Mix Design 2. (Aggressive environment)
Exposure class: XF4,
Strength class: 40 MPa
W/c-ratio: 0,38-0,42
Mix Design 3. A typical SCC mix design for floor purposes and for pre fab purposes:
Exposure class: To be specified
Strength class: To be specified
W/c-ratio: To be specified

Using 1 m^2 of a concrete panel as the functional unit, different options may be mapped:

- hollow core slap
- façade panels

As the work proceeds durability and other properties for the 3 proposed Mix Designs will be considered

7.3 Life cycle definition

7.3.1 Life cycle stages

The life cycle stages of concrete products are shown in figure 7.2. From this it can bee seen that concrete are used for many different purposes.

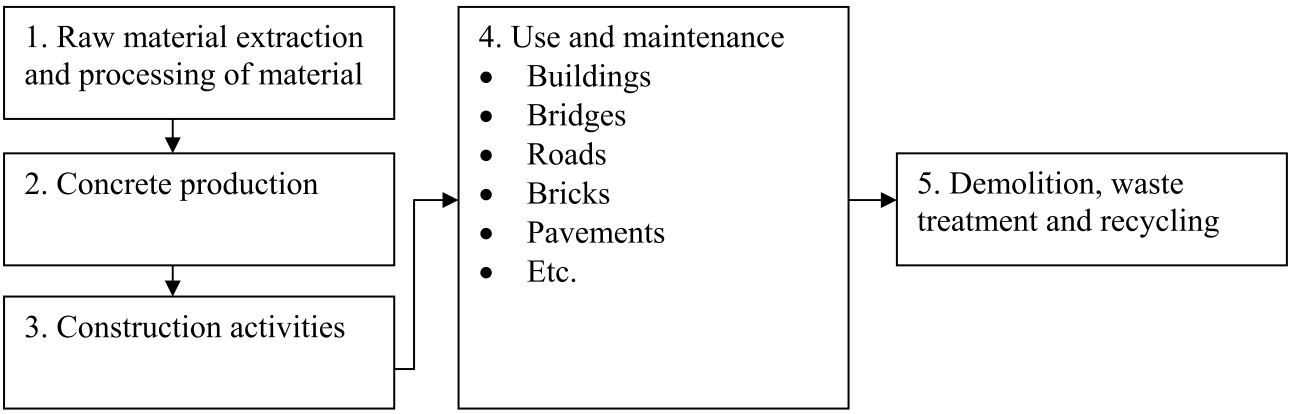


Figure 7.2 Life cycle stages of concrete products

7.3.2 Important life cycle steps

Focusing on the concrete production the use of materials and especially cement and blended cement is important.

Regarding the working environment especially noise and vibrations are important.

Recycling of demolished material is both important from an environmental point of view as well as from en economical point of view.

The main issues are shown in table 7.1.

Table 7.1 Important issues in the concrete production

	Cause
Environment	Material minimisation Minimisation of cement Recyclability
Working environment	Noise and vibrations
Productivity /competitiveness /quality	Durability Recyclability Cost of materials

7.3.3 Important influences

Cluster 3 has in the Baseline report from June 2004 given an overview of the societal and economical issues associated with environmental impacts for concrete production. This is shown in Table 7.2.

Table 7.2 Important influences

Environmental impact category	Societal issues	Economical issues
1) Land-use and exploitation of natural resources (excavations, quarrying, ground water, lime stone). Mainly connected with the production of concrete constituents.	Recreation vs. industry. Planning of land-use. Utilisation of scarce resources.	Transport distances. Use of local materials vs. imported materials.
2) Waste products from concrete production (washing/mixing water, cement slurry, form oil, rejected concrete and excess production)	Land filling with the risk of leaching of heavy metals and hydrocarbons. Sorting and reusing.	Landfill taxes. Recycling into production. Demand from other industries.
3) Emissions and energy consumption (CO_2, SO_2, embodied energy throughout production, transport and construction)	Commitment to reduce greenhouse effect and to behave in an energy conscious manner.	Energy taxes. Up-to-date production equipment and methods.
4) Working environment (noise, vibrations, dust, accidents...)	Health problems.	Expenses for hospitalisation and sick leave. Automated production equipment and methods.

7.3.4 Selection of indicators

The indicators selected for concrete by Cluster 3 is listed in Table 7.3.

Table 7.3 Indicators for concrete production.

	Indicator	Unit per functional unit	Method
External environment	CO_2 emission	kg	Estimated based on the clinker content and the amount and type of consumed energy resource
	Energy	MJ	Energy consumption of concrete production converted to primary energy can be compared.
	Use of mineral based form oil	kg	The amount of mineral oil can directly be compared.
Working environment	The use of SCC	%	
	Noise	Hours at 80 dB(A) or above	Directly comparison of number of hours . If measurement at different levels are available the number of equivalent hours at 80 dB(A) can be calculated
	Dust	mg/m^3 in the working area	Comparison of the total amount of dust and the fraction of quartz, that has a particle size less than 5 microns.
Productivity/competitiveness /quality	Costs	Euro/unit	The cost in monetary terms can be compared directly, when it is specified what costs are included.

Notes to Table 7.3:

The proposed indicators mainly focus on the manufacturing of concrete.

8. Cluster 4, Pavement

8.1 Introduction

Cluster 4 deals with the use of alternative materials in pavement production as fuels or raw materials and the resulting environmental behaviour of the produced cement.

In Figure 8.1 activities in Cluster 1 are related to activities in the other clusters. Relationships are seen in a life cycle perspective.

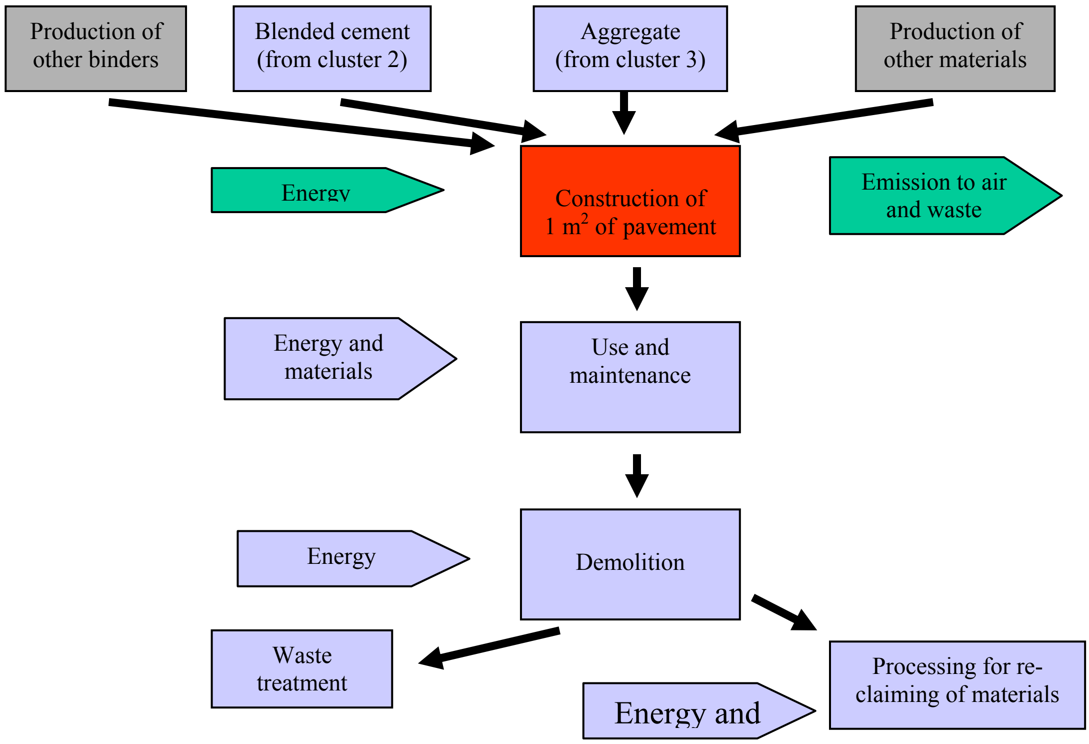


Figure 8.1 Activities in Cluster 4 seen in a life cycle perspective

From Figure 8.1 activities in Cluster 4 regarding pavement do not affect the work in cluster 3, Concrete, - but do include Cluster 1 and 2 and 3, aggregates. Activities in Cluster 1, 2 and 3 will affect the later stages in the life cycle such as maintenance, demolition, waste treatment and recycling.

8.2 Goal and scope

8.2.1 The central question

The central question in cluster 4 is:

To select the most suitable approach for design of low strength cementitous base course layers (much as to minimise binder consumption and to increase the use of local aggregates)

The indicators should therefore be focused on:

- binder consumption
- extent of the use of local aggregates.

These are important parameters for the external environment and for economics as well.

Of course, no other negative effects (environmental, social, economical) should occur in the life cycle of the pavement. E.g. lowering the material consumption should not result in more maintenance (with more material consumption), or the use of local aggregates to decrease transportation should not result in a choice for materials that require more mining energy. These aspects should be monitored, too. Correct technical performance (e.g. equal or more durable than traditional pavements) is a prerequisite.

8.2.2 The functional unit

To measure and express the indicators, these will be related to a so-called functional unit.

The functional unit is established as :

1 m^2 of 'Eco-Serve' pavement for European road classes:

- *motorways [60 y]*
- *highways [60 y]*
- *heavy duty pavements […y]*
- *low volume roads [… y]*

An 'eco-serve' pavement focuses on base course, but it takes also into account the impact of the base course on the whole pavement

8.2.3 Technology options

The following alternatives will be studied:

- Various types of binders (cement, possibly alkali-activated slag)
- Various types of local aggregates

The consequences of a specific design on the whole pavement (e.g. amount of top layer material) will be included too.

8.3 Life cycle definition

Which effects could occur in the life cycle of pavements?
Three issues have to be identified before the indicators can be formulated:

- the life cycle stages and processes where binder consumption and local aggregates are most important in the life cycle of pavements;
- possible other effects that can occur in the life cycle and could positively or negatively influence the (environmental / social / economical) performance;
- possible changes in materials other than in the base course (e.g. top layer).

8.3.1 The life cycle stages

The life cycle of pavements are shown in Table 8.1, where also the most important issues on environment, working environment and productivity/competiviness/quality are shown for each life cycle stage.

Table 8.1 Life cycle stages of pavements

Influence on	**External environment**	**Working environment**	**Productivity / competitiveness / quality**
Life cycle stage			
Raw material acquisition / aggregates production	Transport of aggregates (distance and method) NB: location dependent! Land use	working conditions at quarry (noise, dust, …)	
Concrete production / road design	Material consumption (mix and road design), especially aggregate type and amount (depletion of resources, land use effects) and cement type and amount (CO_2, emissions, energy). Amount of asphalt	-	
Construction activities		-	Initial costs (including material and transport)
Use & Maintenance	Material consumption, esp. aggregates and cement (amount and type), and asphalt Transport of aggregates (distance and means) Leaching	-	Life cycle costs (including material and transport costs)
Demolition and waste treatment (disposal / reuse)	Transport to recycler (?) Material consumption (recyclability and landfill/waste)	-	Recycling costs (costs for recycling vs costs for landfill)

8.3.2 Important effects

The most important issues related to the overall activity "pavement" in Table 8.2 are related to the environment effects and not to the working environment or productivity.

Table 8.2: Important effects

Potential effect in pavement life cycle	Caused by (important processes)
Emissions (a.o. CO_2)	Transport of aggregates Binder production Production of materials other than base course (e.g. top layer)
Depletion of resources	Transport of aggregates Binder production Production of materials other than base course (e.g. top layer)
Land use	Mining of primary aggregates
Energy	Transport of aggregates Binder production Production of materials other than base course (e.g. top layer)
Ecotoxicity	Leaching during use (aggregates, binder)
Waste	Recyclability / landfill
Total life cycle costs (mainly initial costs and maintenance costs)	Amount and type of materials in the whole pavement Construction activities Both initially and during maintenance

8.4 Indicators

8.4.1 Important influences

- Environmental indicators:
  - Indicators for transport should be related to transport distance of aggregates to concrete production and/or to site. Transport should be related to depletion of resources and emissions.
  - Indicators for material consumption should be related to aggregate, cement and ashpalt, in the road design as well as in the maintenance phase. Amount only is not a good indicator, since the type of material also influences the external environment. The type of aggregate influences the depletion of resources and land use effects; the type of cement influences (mainly) energy consumption and emissions (CO_2 is an important one).
  - As environmental side-effects could be monitored:
    - land use
    - leaching (is the leaching influenced by using certain aggregates or cement types?)
    - recyclability (or final waste) and transport to recycler (is the recyclability and transport influenced by the design)

- Working environment indicators: no negative impacts expected or no objective parameters available
- Economical indicators:
    - Initial costs and life cycle costs should be considered in order to cover both transport and material consumption

8.4.2 Arguments for potential indicators

- *transport of aggregates (as parameter for local aggregates)*
  This covers part of the emissions, depletion of resources and energy (and costs?).
  The effect of transport depends on the amount of material to be transported, the transport distance and the transport method. The proposed unit is t.km truck-eq per m^2 of pavement. For example: 500 tonnes of aggregate transported over 100 km by truck, is 5000 t.km. Since some materials are transported (partly) by ship or train, a truck-eq will be established (based on energy consumption).
  Since transport distances are location-dependent, it has to be decided if a generic pavement location has to be defined with generic transport distances, or if the indicator will be established for specific sites. An other opportunity could be to express the indicator as a percentage change in t.km transport relative to a reference road per country; assuming that measured percentages do not differ between countries.
- *CO_2-emission*
  The binder (cement) covers an other important part of the emissions, depletion of resources and energy (and costs?). The effect of cement depends on amount of cement and cement type.
  CO_2 is one of the important parameters in cement production. Furthermore, it is important in asphalt production. CO_2 is also related to energy use.
  The proposed unit is tonnes of CO_2-eq per m^2 of pavement, assuming no large differences in the cement type used. The CO_2-eq factors will be supplied by task 2 in order to include the effects of other greenhouse gases also.
- *amount of aggregates*
  The use of primary aggregates is related to land use. The type of aggregate is important for the land use effect (some aggregates have higher effects than others; secondary aggregates differ from primary). The differences are difficult to quantify, esp. between the primary aggregates. It is proposed not to distinguish between primary aggregate types, but only between primary and secondary. It is suggested to regard the amount of primary aggregates as a side-effect (it is not an objective in itself) and to monitor it on a qualitative scale (expected increase, decrease or similar effect expected in comparison to a reference pavement).
- *leaching*
  Leaching is difficult to quantify in one score. The amount of material does not cover it, since the material type seems to be more important for the leaching effect. Since leaching can be considered as side-effect (it is no objective in itself to reduce leaching, but it has to be checked if leaching will not increase), it is sug-

gested to monitor it on a qualitative scale (expected increase, decrease or similar effect expected in comparison to a reference pavement).

- *waste*
  Waste reduction is also not a goal in itself in cluster 4. However, it could be a side-effect. It has to be checked if the amount of waste in the life cycle is not increased by certain pavement designs. It is suggested to monitor this also qualitative by the recyclability (higher recycling percentage, lower recycling percentage or similar recycling percentage expected in comparison to a reference pavement).

8.4.3 Selected indicators

From the evaluation is learned that monitoring some of the parameters/processes in the life cycle could largely cover the expected effects on sustainability. The suggested indicators are therefore as shown in table 8.3.

Table 8.3 Selected indicators for pavement

Indicator	Unit	monitored side-effect
transport of aggregates from quarry to production/construction site	t.km truck-eq per m^2 of pavement (whole life cycle), established for a 'reference' pavement location (e.g. national representative)	amount of primary aggregates (↑ / ↓ / =)
CO_2 emission related to raw materials	t CO_2-eq per m^2 of pavement (whole life cycle)	Leaching (↑ / ↓ / =) Waste (↑ / ↓ / =)
Life cycle costs	% relative to a reference pavement	

9. The construction Industry

The purpose of this chapter is to present those indicators that are relevant for the hole life cycle of a construction, - for instance a building of a specific type of concrete or a specific type of road.

Only a few indicators are meaningful for all the parts of the lifecycle and all the activities in the clusters. Those, which are, are here presented as general indicators. Other indicators are very relevant and do give important information regarding environmental aspects, - these are here presented as specific indicators.

9.1 General indicators

General indicators mean indicators that are relevant for all clusters and for most activities in the life cycle of constructions. Only indictors relevant for Eco-Serve and the construction industry are mentioned.

9.1.1 Energy

Consumption of energy is a key-issue for most activities. Energy is consumed for

- clinker production,
- winning and processing aggregates,
- mixing processes and
- transportation

The use-phase, which for instance includes many years of heating and/or cooling a building, is often the largest energy consumer. This is not included in the considerations of the Eco-Serve project, but can be taken into account.

Different types of energy are used as for example electricity, diesel oil or alternative fuels.

In order to ad these different types of energy together the amount of primary energy is calculated. Primary energy means the total amount of energy spent including losses for transformation etc.

Tools for calculating primary energy are established based on data for consumed electricity, consumed oil and gas for processes and transportation as well as other necessary conversions, - see chapter 4.

9.1.2 Carbon dioxide

Emission of carbon dioxide is another relevant indicator. The amount of carbon dioxide does to some extend picture the amount of consumed energy. Never the less not all sources of energy cause the same amount of carbon dioxide per unit of energy.

In the context of the construction industry, issues as carbon dioxide formed by the clinker production and the use of secondary materials are important activities.
To measure the indicator for carbon dioxide simple tools are developed. The necessary inputs are for example:

- Amount and type of spent energy for transportation and processes
- Amount of clinker content

9.2 Specific indicators

9.2.1 Clinker content

The content of clinker is an important issue in the concrete industry. The production of clinker consumes energy and carbon dioxide is released from the calcination process.

This means that the environmental effects from the clinker production are included in the indicator for carbon dioxide as well as for energy consumption, and therefore, there is no need for a special indicator for the clinker content. Information about the amount of clinker is important data used for calculating the carbon dioxide indicator (see section 4.2).

Blended cement in relation to LCA is a question of the amount of clinker and other materials used and if the blending takes place when producing blended cement or concrete.

9.2.2 Leaching

Leaching of hazardous substances from concrete during use is pointed out as an important parameter.

Hazardous substances may be introduced by using alternative fuels and other materials by production of clinker and by using alternative filler materials for blended cement.

No simple indicator has been developed. Changes in leaching of a set of substances, primarily heavy metals, have to be assessed. The assessment has to include factors as mobility of the substances and toxicity as well as the use of the local area (e.g. ground water interests) and national legislation.

Leaching from two different types of concrete can be compared relatively easily if other circumstances are the same.

9.2.3 Land use

Land use in relation to winning of aggregates has been considered as an indicator, - but a way to measure this in practice has not been found.

9.2.4 Amount of surplus material

When winning of aggregates, fine surplus material can be relevant to consider. If the surplus material can not used for other purposes it has to be regarded as waste.

In indicator for surplus material is:
used material [kg] / total extracted material [kg]

9.2.5 Binder consumption and local aggregates

When producing concrete focus is on binder consumption and local aggregates.

By using the two general indicators, energy and carbon dioxide, a change in the amount of binder will be measured.

Transportation of aggregates is also important. The shorter the distance of transportation is, the smaller amount of energy is consumed. Using local aggregates will therefore be shown in both the indicators for energy and for carbon dioxide.

9.2.6 Recycling of materials

Recycling of demolished material is important in the construction industry. Never the less, an indicator measuring the use and reuse of materials in the whole lifecycle has is not been included in the Eco-Serve activities.

9.2.7 Other environmental issues

Durability could be regarded as an indicator, but durability is very often part of the functional unit, where the service of the product is defined. For instance, if one type A of a road has a durability of 20 years and type B has a durability of 40 years, you have to compare two A with one B to obtain the same service.

9.3 Other indicators

9.3.1 Working environment

The clusters have assessed indicators measuring the performance for the working environment.

Some have found the indicator “work hours lost due to accidents or work related disease per functional unit” relevant.

Indicators measuring the damages from vibrations are relevant considering self compacting concrete and the amount of dust is relevant handling aggregates. These indicators are considered for the relevant activities, but not for whole life cycle in general.

Others have found it very difficult to identify indicators for which data are easily retrieved.

9.3.2 Productivity

The clusters have assessed indicators for productivity, competitiveness and quality.

An indicator expressing productivity in terms on spend man hours per produced unit can be relevant for some activities. Never the less, data can not be expected to be available for the whole life.

Regarding competitiveness cost of materials per construction unit has been considered. Due to confidentiality of most data this indicator seems not to be applicable.

A central indicator for quality is durability expressed by the lifetime of the construction expressed in years. To this comes the necessary maintenance.

References

Berrig A, Mathiesen D, Frantsen EB (2002) Improved resource utilisation of Danish raw materials, Danish Agency for Forestry and Nature.

Broers, J., Improving and testing a land use methodology for LCA, Ministerie van Verkeer en Waterstaat, The Netherlands, 2002

Conway-Schempf N. Case study: Economic Input-Output Life Cycle Assessment of Asphalt versus Steel Reinforced Concrete for Pavement Construction. Carnegie Mellon University, Pittsburg, PA 15213.

Danish guideline for the working environment, No. 9, Construction industry (Arbejdsmiljøvejviser nr. 9, jord, beton og belægning, Arbejdstilsynet)

Danish guidelines for threshold limits, 2002. (Grænseværdier for stoffer og materialer, C.0.1. Arbejdstilsynet, oktober 2002)

FIP, Environmental effects of concrete, State-of-the-art report prepared by Task Group 3.4, March 2003, Switzerland

Glavind M and Riis K (2000) Gathering of environmental data for light clinker concrete with respect to LCA (in Danish)

Glavind, M., and Munch-Petersen, C., 2002, 'Green Concrete' - a life cycle approach, Challenges of Concrete Construction, Dundee

Glavind, M., Jesper, S.D. and Röttig, S. 2001, Cleaner Technology Solutions in the Life Cycle of Concrete Products (TESCOP), Brite-Euram project BE 3858/BRPR-CT97-0385. DTI, Building Technology Carl Bro Group. 1995 Industry Analysis, Concrete Cleaner Technology in concrete production. Main report: Environmental impact and life-cycle analysis.

Guidance for Preparing National Sustainable Development Strategies; World Commission (1987)

Hansen G and Glavin M (2001) Vibration-free concrete (in Danish) Danish Technological Institute, Concrete Centre

Health and Safety Statistics (2001) HMSO. ISBN 0717621103

Jasch, C., 2000, Environmental performance evaluation and indicators, Journal of Cleaner Production, Volume 8, Pages 79-88

Lanser, P., Seminar 'Concrete for the environment', April 9 2002, Stockholm, Sweden. For more information: call CEMBUREAU: +32 2 234 1022

Life Cycle Inventories for Packaging (1998) Swiss Agency for the Environment, Forests and landscape. Environmental Series No. 250

MMSD, Breaking new ground. The report of the Mining, Minerals and Sustainable Development Project, May 2002, Earthscan Publications Ltd, London

Molen, B. van der, Richardson, A. and Voogd, H. 1998, Mineral Planning in a European Context, GeoPress, The Netherlands

Mûller C and Siebel E (2004) Eco-Serve Cluster 2: Production and application of blended cements. Presentation at the Eco-Serve-network meeting, Sittard 04/05.11.2004

Nielsen CB, Schaumann J, Hvorslev S, Sejersen P (1998) Environmental screening of sewer pipes made of different materials (in Danish). Working report no. 3. Danish Environmental Agency.

Pommer K, Bech P, Wenzel H, Caspersen N, Olsen S I (2003) : Handbook on environmental assessment of products, Environmental Project no. 813, 2003, Ministry of Environment. Danish Environmental Protection Agency

Schuurmans, A., et al., Bruikbaarheidstoets NEN 7185 mmg voor de GWW-sector, reported by INTRON to Rijkswaterstaat DWW, July 17, 2002 (published as a part of an internal report of DWW)

Schuurmans, A., Rouwette, R. en Vonk, N., Milieuaspecten fijner zand in beton. (in Dutch), Den Haag : Ministerie van verkeer en Waterstaat, 2003, DWW-2003-041, Publikatiereeks grondstoffen 2003/09, Cement vol. 55 (2003), 4, p. 71-72 (2) (in Dutch)
Article to be published in Int. J. LCA, 2004 (currently in review process)

Spangenberg, J.H., et al. 1998, Material Flow-based Indicators in Environmental Reporting, European Environment Agency, Wuppertal

Stripple, H (2000) Life Cycle Inventory of Asphalt Pavements. For the European Asphalt Pavement Association (EAPA) and Eurobitume. ILV, Swedish Environmental Research Institute, Gotenburg.

The cement sustainability initiative. Our agenda for action, July 2002, www.wbcsdcement.org

Vold, M. and Rønning, A., LCA of Cement and Concrete - Main Report, Stiftelsen Østfoldforskning, Fredrikstad, 1995

Walker, J., Howard, S., MMSD, Finding the way forward. How could voluntary action move mining towards sustainable development?, ERM, World Business Council for Sustainable. Development, IIED, London, 2002

Westling M (1999) Functional properties of concrete roads – a state of the art report , CBI rapport/report 1:99

World Commission on Environment and Development: Our Common Future, 1987, p.43