



# Summary of Environmental Baseline and Best Available Technology

ECO-SERVE Network, Task 2

November 2004



ECOserve

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## 1 INTRODUCTION

This report is a deliverable of Task 2 “Environmental Baseline and Indicators” of the ECO-serve Network. It relates to subtasks 2.1 and 2.2 according to the Work Plan for Management and Co-ordination dated May, 2002.

Following the introduction, four chapters are devoted to summarize the findings of the four clusters of the Network.

The summary report is written by the following working group:

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However, most of the input is gathered from the individual clusters, which is kindly acknowledged.

### 1.1 Background and scope

The ECO-serve Network is financed from the European Commission under the 5<sup>th</sup> Framework Program. Reference is made to [www.eco-serve.net](http://www.eco-serve.net).

The 4 clusters of the Network are (Figure 1.1 and 1.2):

1. Alternative materials in cement production
2. Blended cements
3. Concrete and aggregate production
4. Pavements

Task 2 is an activity of ECO-serve crossing over the clusters in an effort to describe and formulate environmental indicators.

In a recent paper from the EU (COM, 2001<sup>1</sup>) the following statement was made: “The global implementation of sustainable development requires more particularly: the design, development and dissemination of technologies making it possible to *ensure more rational use of natural resources, less waste production and a reduction in the impact of economic activity on the environment.*”

The quote given above show that sustainable development will be of major importance in government policies in the coming years and several EU member states have formulated policies aimed at securing environmentally sustainable industries. The ECO-SERVE Network will help to convert these policies into practical applications.

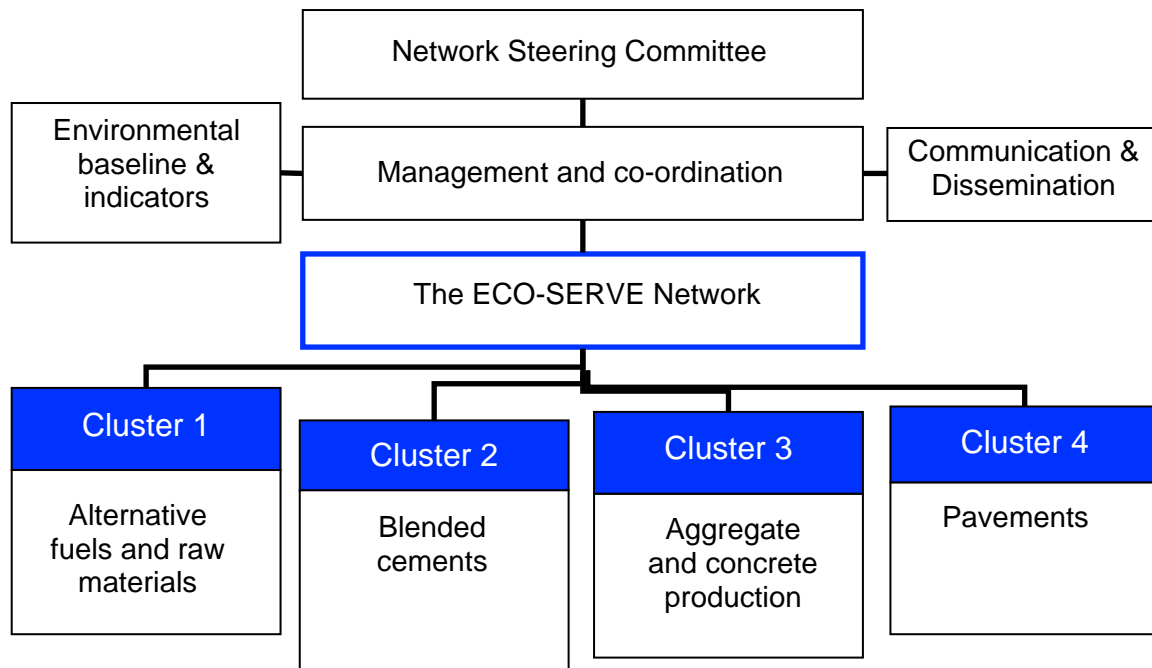


Figure 1.1 Organisation of the ECO-serve Network in clusters. Task 2 is organised under Management and co-ordination.

However, it should be noted that the above-mentioned quote also reflect a holistic approach where the sustainable development should include all aspects throughout the life cycle of a building/construction. Hence, to obtain an overall sustainable construction the knowledge of the environmental impact of various material choices should be connected with the structural design in order to optimise its environmental profile. Sometimes diverging needs are encountered during this process, for instance the wish to make slender walls, saving building materials diverges with the wish to make energy efficient buildings, requiring thick walls.

The holistic approach is further described in the main report of Task 2<sup>2</sup> where indicators are presented to quantify the different environmental impacts of cement, aggregates and concrete production throughout the full life cycle.

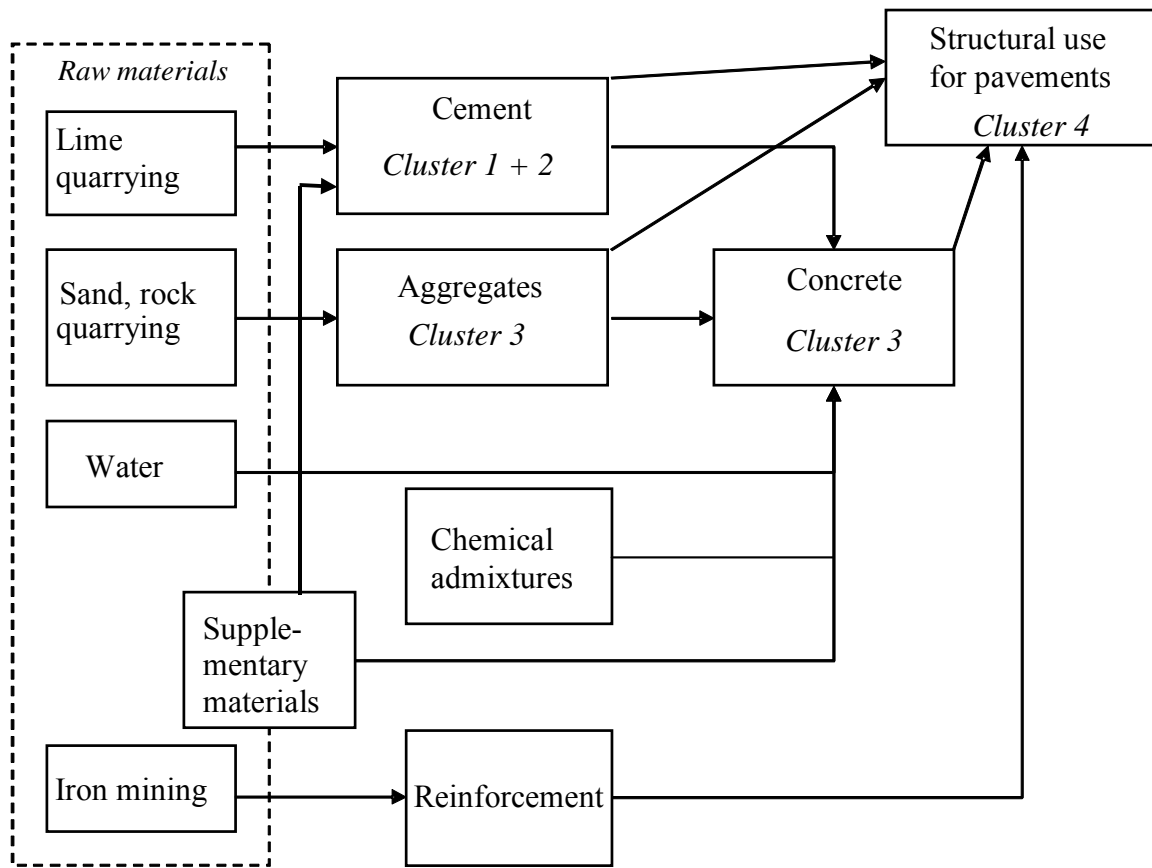


Figure 1.2 Constituents of concrete and its inter-relationship within the ECO-serve Network.

## 1.2 Objectives

The overall objective of Task 2 is to create a pan-European baseline for the BAT with respect to the production and use of cement, aggregate, concrete and pavements throughout a whole life cycle. Furthermore, Task 2 should establish environmental indicators for innovative cement, aggregate, concrete and pavements.

This report is meant to summarise the work on the environmental baseline that have been carried out in the four clusters.

## 2 Cluster 1: Alternative Materials in Cement Production

### 2.1 Scope

The cement industry produces cement clinker in kilns that are fired. For this purpose different energy sources can and are used. The most predominantly conventional used energy sources are coal and gas. Alternative energy sources can substitute the conventional ones to an extent. In more and more countries waste flows from other parts of the economic society are being used for this purpose. Doing so may influence:

- the need for non-renewable resources;
- the logistics;
- the production process itself;
- the emissions;
- the properties of the cements produced;
- the leaching properties during the life cycle.

If a 'good' alternative energy source can be applied, how do we define good from an environmental point of view?

This leads to the central question for Cluster 1 and can be expressed as:

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

In literature several technologies concerning the use of alternative fuels for the production of cement clinker in kilns are described.

Figure 2.1 gives an overview of alternative fuels for the production of cement clinker in kilns.

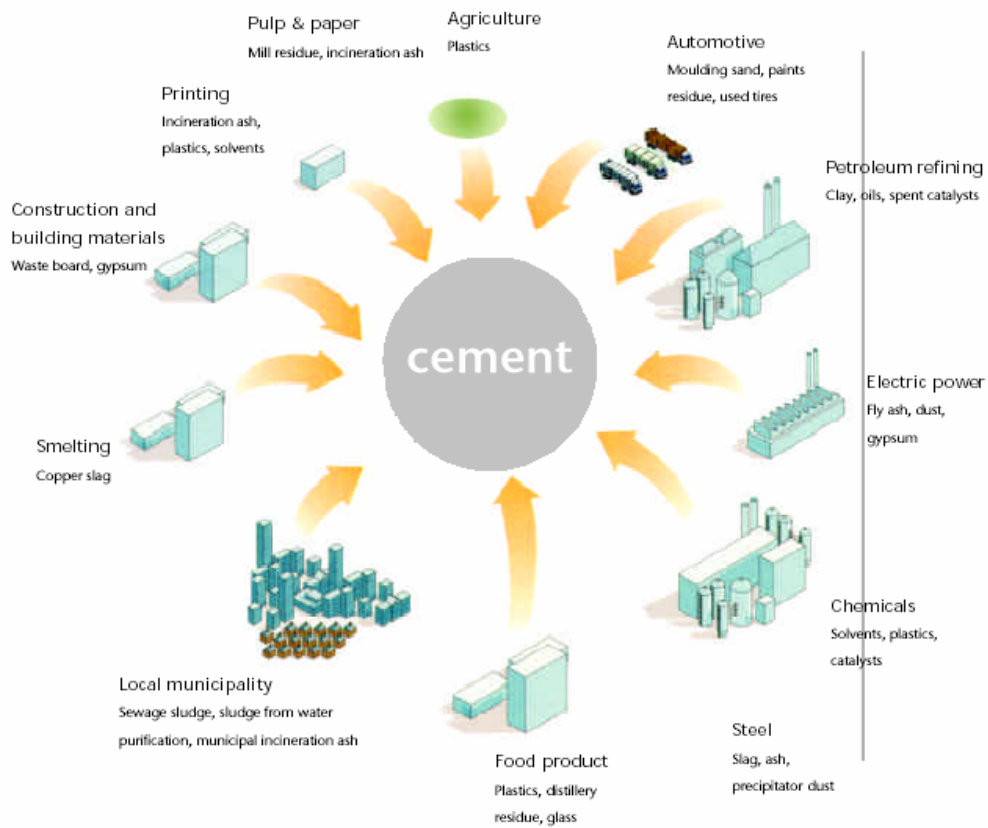


Figure 2.1 Overview of possible alternative fuels<sup>3</sup>.

## 2.2 Technologies for alternative fuels

From Fig. 2.1 four groups of alternative fuels have been selected as the most interesting and will be discussed below:

- Tires
- 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.)
- Meat and bone meal, animal fat

The influence on the environment can be categorised into the different phases of the life cycle of concrete (Table 2.1).

Table 2.1: Important life cycle stages in Cluster 1.

Influence on	external environment	working environment	productivity / competitiveness / quality
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 <sub>2</sub> , NO <sub>x</sub> 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)

To gain insight into the effects of the possible alternative energy sources the following items mentioned in table 2.1 are discussed below

- Emissions from the production of clinker
- Leaching during use, demolition, recycling and waste treatment
- Amount of fossil fuel replacement

Note that all comparisons in this chapter are based on publicly available literature. The results hint at possible changes. Since the comparisons are based on different literature sources, the comparison is mainly an indication or trend. Furthermore, for every comparison assumptions are made for reasons of simplification. This is of course reflected in the results: they are simplified. Apart from the aspects studied, the comparison is not complete. Assertions towards availability of alternative fuels, logistics and costs are just three examples of aspects that have not been studied. The results of the use of alternative fuels have to be put into practice in a small scale to study its effects on large scale.

### Emissions from the production of clinker

During the production of clinker emissions to the air are emitted. The emissions can be divided into three categories<sup>4</sup>. Note that some of these issues are also treated under Cluster 2.

Category 1 contains the emissions due to the production process itself. (CO<sub>2</sub> emissions). During the calcination reaction ( $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$ ), about 60 % of the total CO<sub>2</sub> emission is emitted to the air. Category 1 emissions are independent of the energy source and are therefore not taken into account here. Refer to Chapter 3.

Category 2 contains the emissions emitted through the combustion of the energy sources (with CO<sub>2</sub> and NO<sub>x</sub> as the most important emissions). Typically 30 % of the total CO<sub>2</sub> emissions are emitted to the air through this way<sup>4</sup>.

Category 3 contains the emissions by means of the production of electrical power (used for grinding) and the emissions emitted during transport of the raw materials and energy sources to the production plant. Typically 10 % of the total CO<sub>2</sub> emissions are emitted to the air through this way<sup>4</sup>. Category 3 emissions are dependent on the energy source. However the expected reduction of this emission due to a change in energy source will be negligible and is not taken further into account.

The Dutch Standard<sup>5</sup> for drawing up environmental data for construction materials prescribes that the following emissions to the air must be included when using thermal heating:

- CO<sub>2</sub>
- CO
- NO<sub>x</sub> (NO<sub>2</sub> and N<sub>2</sub>O)
- SO<sub>2</sub>
- C<sub>x</sub>H<sub>y</sub>
- PM<sub>10</sub> (particles < 10 μm)

These emissions are relevant for the production of cement.

To gain insight into the effect of the possible alternative energy sources for the emissions from the production of clinker the emissions from the production of clinker with traditional energy sources are compared to the emissions from the production of clinker with alternative sources.

The theoretical energy consumption for the burning process (chemical reactions) is about 1750 MJ/ton clinker<sup>6</sup>. Assuming that the traditional energy sources consists for 100 % of gas the production of 1 kg clinker with traditional fuel leads to the following emissions (Table 2.2).

Table 2.2: Indicative emissions with various energy sources related to the combustion process in the kilns. (Sources: VLCA database<sup>7</sup>, IVAM 3.0 database<sup>8</sup> for PE data)

<b>Fuel types</b>	<b>Conventional</b>	<b>Tires</b> (Section 2.2.1)	<b>Waste oil</b> (Section 2.2.2)	<b>PE</b> (Section 2.2.3)
Emissions for the production of 1kg clinker (g)				
CO <sub>2</sub>	11E+01	11E+01	37E+01	11E+01
CO	3.0E-02	4.0E-02	1.1E-02	1.0E-02
NO <sub>x</sub>	6.5E-02	1.0E-02	3.6	2.2E-01
SO <sub>2</sub>	6.0 E-02	>> higher, due to S in tires	2.8	1.3E-03
C <sub>x</sub> H <sub>y</sub>	1.1E-04	1.0E-02	5.0E-02	NA
PM <sub>10</sub>	1.8E-05	4.0E-05	0.8	NA

## Leaching during use, demolition, recycling and waste treatment

Leaching is the process in which a release of contaminations from a building material into the environment (soil, water) takes place, due to contact with water. Leaching is not related to the production process of the clinker, but is related to the use, the demolition and the recycling of the construction/material in which the cement is applied.

For each material a set of 'critical' leaching parameters can be identified. For cement bounded materials these parameters are barium, sulphate and fluoride. The possible effects of the use of alternative fuels in the critical set of leaching parameters are described below for each of the alternative fuels<sup>a</sup>.

A quantification of the leaching problem of ordinary portland cements is given in the ECN (Energy research Centrum, the Netherlands) study "Environmental criteria for cement based products ECRICEM Phase I"<sup>9</sup>. However, unfortunately the results of this study are not yet public.

In Europe several countries (for example the Netherlands, Belgium and France) use different testing methods for determining the leaching values of building materials. The Netherlands is the only county in which limiting leaching values are laid down in a standard (the Dutch Building Decree)<sup>a</sup>.

## Amount of fossil fuel replacement

The production of cement in the European Union was about 172 million tonnes in 1995, equivalent to about 12 % of world production. With this figure in mind the potential of every alternative fuel to substitute the conventional fuels can be assessed.

### 2.2.1 Use of tires as alternative fuel

#### Emissions from the production of clinker

To compare the emissions related to the production of clinker with traditional energy sources and the emissions related to the production of clinker with alternative energy sources it is assumed that the same amount of energy in put is needed for the production. (1.75 MJ/kg clinker<sup>6</sup>) The energy content of rubber is 43.3 MJ/kg<sup>10</sup>. This means that for the production of 1 kg clinker 0.04 kg tire material is needed for combustion.

In Table 2.2 the emissions from the production of 1 kg clinker with a traditional energy source are compared with the emissions from tires as alternative energy source. For an overview of the CO<sub>2</sub> emissions from the production of 1 kg clinker related to various alternative fuels for combustion see Fig. 2.3.

<sup>a</sup> Hofstra U, INTRON, the Netherlands

## Leaching during use, demolition, recycling and waste treatment

During the combustion process the ashes end up in the clinker. Tires contain zinc. Zinc can be a critical leaching parameter. When fibre reinforced tires are used for the combustion process chromium and nickel can also be critical parameters<sup>b</sup>.

## Amount of fossil fuel replacement

In 2001 the number of collected tires in Europe was 2,542,640 ton<sup>c</sup>. 14 % of this amount is used for thermal combustion. For the production of 172 million tonnes clinker about 3E+11 MJ is needed. If all the collected tires are used for the production of clinker 5 % of the total energy need is fulfilled.

## Interpretation

Regarding the emission the use of tires as an alternative fuel changes the emission pattern. Based on the energy content tires seem a relevant alternative fuel. For large scale substitution the availability of tire material is not sufficient.

Regarding leaching of zinc there may be a problem if tires are to be used as alternative fuel. Further investigation on this topic is needed.

## 2.2.2 Use of waste oil, other organics (oil mud, organic distillation residues) as alternative fuel

### Emissions from the production of clinker

Because of the wide range of waste oil types it is hard to predict the average energy content of waste oil. For example the waste oil flow "silt/water/oil mixture" can contain up to 75 % water. Meaning a reduction of the energy content of 75 %<sup>d</sup>. Assuming that waste oil has an energy content of 1/3 of primary oil, the energy content of the waste oil is estimated to be about 14 MJ/kg. This means that for the production of 1 kg clinker 0.041 kg waste oil is needed for combustion.

In Table 2.2 the emissions from the production of 1 kg clinker with a traditional energy source are compared with the emissions from waste oil as alternative energy source. For an overview of the CO<sub>2</sub> emissions from the production of 1 kg clinker related to various alternative fuels for combustion see Fig. 2.3.

<sup>b</sup> Hofstra U, INTRON, the Netherlands

<sup>c</sup> www.ETRA.org

<sup>d</sup> www.AOO.nl

## **Leaching during use, demolition, recycling and waste treatment**

The same critical leaching parameters can be expected as those mentioned when traditional fuel is used. Due to storage of the oil mud in drums made of steel the expected leaching of chromium and nickel will be a little higher.

## **Amount of fossil fuel replacement**

In 2000 the supply of waste oil (used oil, oil filters and other sources of waste oil) in the Netherlands numbers 590,000 tonnes. Assuming that the supply in whole Europe lays at least a factor 10 higher than this figure. 55% of the total amount is used for thermal combustion<sup>e</sup>. For the production of 172 million tonnes clinker  $3E+11$  MJ is needed. If all the combusted waste oil collected in the Netherlands is used for the production of clinker 0.02% of the total energy need is obtained.

## **Interpretation**

Regarding the emissions from the use of waste oil as an alternative fuel does not seem an interesting option. The emissions due to the production of 1 kg clinker with waste oil are much higher than the emissions due to the production of 1 kg clinker with a traditional fuel.

Furthermore, the availability of waste oil is limited compared with the need for cement production.

### **2.2.3 Use of industrial and commercial waste (pulp, paper and cardboard, plastics, packaging, etc.) as alternative fuel**

#### **Emissions from the production of clinker**

As a representative of this group of commercial waste polyethylene (PE) is selected as a reference. The energy content of PE is  $42.7 \text{ MJ/kg}^{10}$ . This means that for the production of 1 kg clinker 0.04 kg PE is needed for combustion.

In Table 2.2 the emissions from the production of 1 kg clinker with a traditional energy source are compared with the emissions from PE as alternative energy source. For an overview of the CO<sub>2</sub> emissions from the production of 1 kg clinker related to various alternative fuels for combustion see Fig. 2.3.

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<sup>e</sup> www.AOO.nl

## Leaching during use, demolition, recycling and waste treatment

When plastics, totally built up of hydrocarbons are used, the same critical leaching parameters can be expected as the parameters mentioned when traditional fuel is used. However plastics may also contain metal catalysts, softeners or fire reductors. If metal catalysts are used nickel and chromium can be critical parameters. If softeners or fire reductors are used chloride and bromide can be critical parameters<sup>f</sup>.

## Amount of fossil replacement

Figure 2.2 gives an overview of building materials in the building and construction sector in Western Europe for the year 1995.

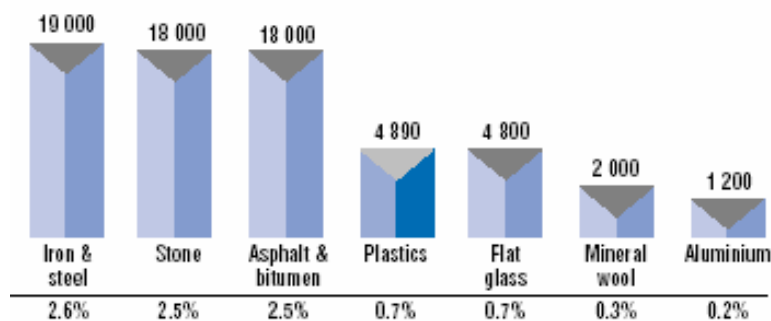


Figure 2.2 Building materials in the building and construction sector in Western Europe for the year 1995<sup>g</sup>.

In 1995, 489 million tonnes of plastic (20 per cent of the total amount of plastic used) was required by the building and construction sector. In 1995, 841,000 tonnes of plastic construction and demolition waste was generated. Of the total amount of plastics waste produced, fixed floor coverings was the highest contributor (274,000 tonnes) followed by fitted furniture (250,000 tonnes), pipes and ducts (96,000 tonnes) and insulation (84,000 tonnes).

For the production of 172 million tonnes clinker  $3E+11$  MJ is needed. If all the plastic construction and demolition waste is combusted in kilns for the clinker production 0.012 % of the total energy request is fulfilled.

## Interpretation

Regarding the emissions from the use of commercial waste as an alternative fuel seems to be an interesting option.. The emissions are more or less equal, except for the emissions of  $NO_x$ , which are higher. However, the supply is far from sufficient. Leaching of nickel, chromium chloride and bromide might be problematic. Further investigation on this topic is needed.

<sup>f</sup> Hofstra U, INTRON, the Netherlands

<sup>g</sup> www.APME.org

## 2.2.4 Use of meat and bone meal and animal fat as alternative fuel

### Emissions from the production of clinker

Emissions from the combustion of 1 kg of animal fat have not been found. In table 2.3 emissions are given for the combustion of animal fat in mg/m<sup>3</sup> air<sup>11</sup>.

Table 2.3: Indicative emissions from combustion of animal fat.

Substance	Emissions (mg/m <sup>3</sup> air)
CO <sub>2</sub>	NA
CO	3,0
NO <sub>x</sub>	37E+01
SO <sub>2</sub>	34 E+01
CxHy	NA
PM10	NA

### Leaching during use, demolition, recycling and waste treatment

The same critical leaching parameters can be expected as the parameters mentioned when traditional fuel is used.

### Amount of fossil fuel replacement

Table 2.4 gives an overview of the production of meat and bone meal and animal fat in Vlaanderen (1998)<sup>h</sup>.

Table 2.7: Overview of the production of meat and bone meal and animal fat in Vlaanderen, 1998

Source	Production animal waste	Production bone meal
Cattle company	71 ktonnes	
Slaughterhouse	5812 ktonnes	
Meat processing industry	35 ktonnes	
Others	17 ktonnes	
TOTAL	705 ktonnes	230 ktonnes

For the production of 172 million tonnes clinker 3E+11 MJ is needed. Assuming that the supply in whole Europe lies at least a factor 10 higher than the supply in Vlaanderen. Due to the cut back of possibilities for recycling of animal fat almost all of the animal fat is burnt. If the total amount of animal fat is combusted in kilns for the clinker production 50 % of the total energy request is fulfilled.

<sup>h</sup> www.OVAM.be

**Interpretation**

Because of the lack of data it is not possible to assess the emissions properly for animal fat as an alternative fuel.

Regarding the supply of animal fat seems to be an attractive alternative fuel.

**2.2.5 Conclusions**

All results in this chapter are indicative and hint at possible solutions. It shows that alternative fuels are available and can substitute traditional fuels to a considerable extend.

It also shows that the emission patterns will change. This will have consequences for permits etc. It also shows that the availability varies greatly.

For an overview of the CO<sub>2</sub> emissions of the production of 1 kg clinker related to the used fuel for combustion see figure 2.3.

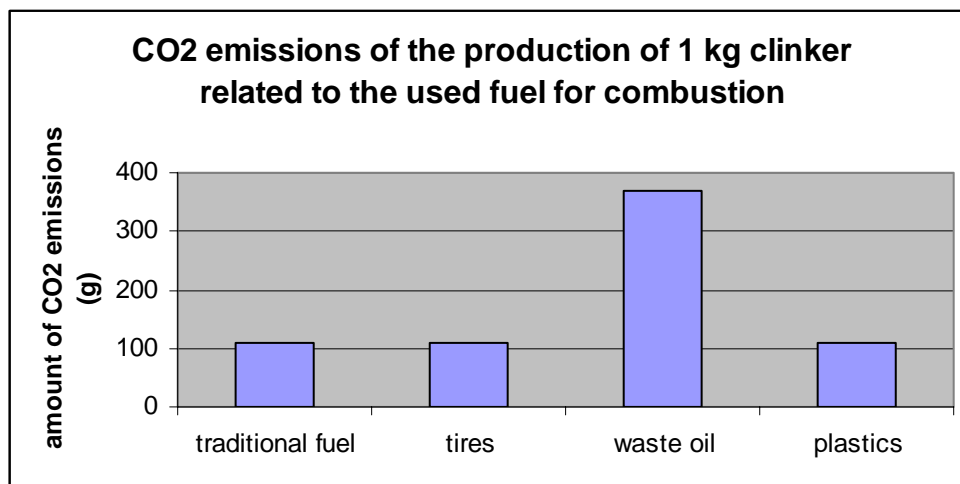


Figure 2.3 CO<sub>2</sub> emissions of the production of 1 kg clinker related to the used fuel for combustion (Table 2.2).

It can be concluded that leaching does not seem to be one of the most critical parameter in the search of sound and sustainable alternative fuels. However, further research into this matter is needed.

## 3 Cluster 2: Blended Cements

### 3.1 Scope

Cluster 2 deals with the production and application of blended cements. Blended cements are defined according to EN 197-1:2000 as cements where part of the clinker content is substituted with other main constituents (denoted CEM II – V). The application of cement for concrete production - both for pure Portland cement (CEM I) as well as various blended cements - is governed by the concrete standard EN 206-1:2002 and corresponding National Application Documents (NAD's). The NAD's are being implemented nationally based on national traditions, durability issues, materials and practical experiences.

Cluster 2 has chosen to work along three tracks:

1. Overview of European production and use of blended cements.
2. Overview of the national application rules across Europe by comparing NAD's.
3. Specific research activities to document the performance of blended cements relative to pure Portland cement.

Only the results of item 1 and 2 are included in the present report since the research activities are still under preparation.

Most of the results and illustrations found in this chapter are taken from a presentation prepared by Christoph Müller and Eberhard Siebel<sup>i</sup>.

### 3.2 Technologies for blended cements

Several technical improvements to reduce the environmental impact of cement production have been reached in the European cement industry throughout the last 2 decades<sup>j</sup>. A promising potential to reduce environmental impact is provided by the reduction of the clinker content (using blended cements). Alternative main constituents for blended cement CEM II are denoted as shown below:

- -S denotes granulated blastfurnace slag.
- -D denotes silica fume.
- -P and -Q denote pozzolanas (natural and calcined respectively).
- -V and W denote fly ashes from power plants (silicious and calcarous respectively).
- -T denotes burnt shale.
- -L and LL denote limestone.
- -M denotes composite where several materials are mixed.

<sup>i</sup> VDZ, Verein Deutscher Zementwerke, Düsseldorf

<sup>j</sup> In 1999 the major cement manufacturers formed a Cement Sustainability Initiative under the World Business Council for Sustainable Development (WBCSD) in order to promote research and development on cement production and sustainability, <http://www.wbcscement.org>

For CEM II up to 35 % substitution of clinker is possible while the upper limit for CEM III is 95 % (Fig. 3.1). Thus, it is possible to produce slag cement with practically no cement clinker at all.

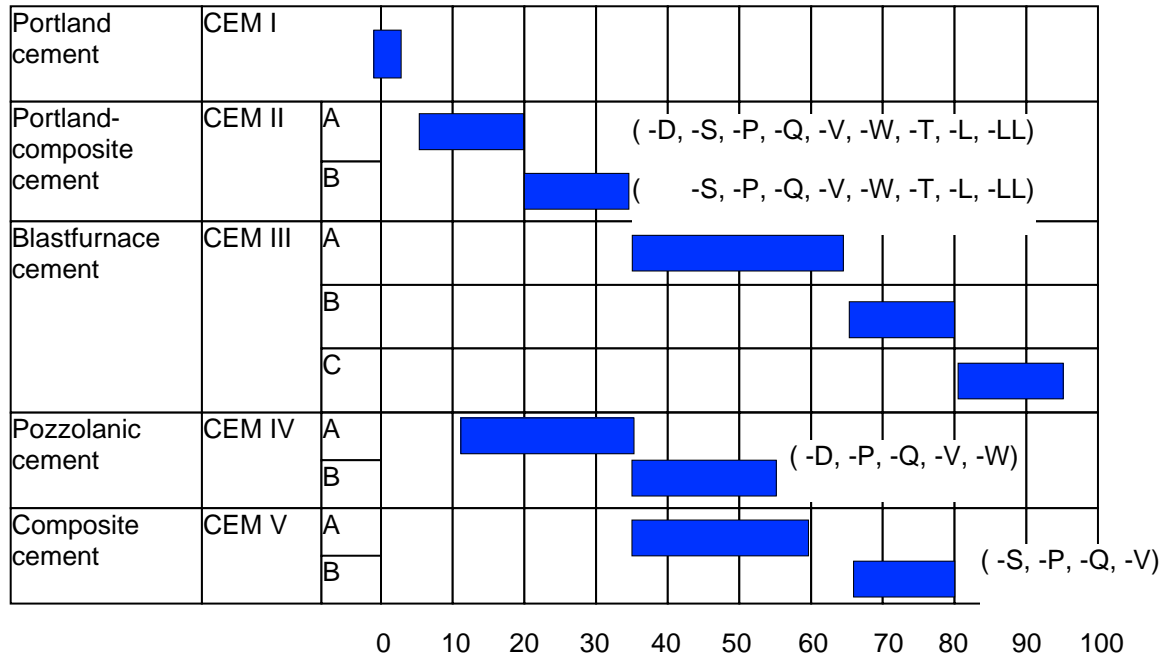


Figure 3.1 Cement types according to EN 197-1:2000. The x-axis shows the amount of main constituent(s) beside cement clinker in weight-%. The letters refer to the description of main constituents given above.

### 3.2.1 Overview of blended cements

Before going to deep into the various blended cements we first take a look on the production/consumption of cement according to the statistics of CEMBUREAU<sup>k</sup>. The CEN standard EN 197-1 subdivides cement into 5 types (CEM I-V) depending on the blend and further into 3 strength classes (Fig. 3.1 and 3.2) The total 2001-production of 176 million tonnes is distributed on the ordinary and on the high strength class with about 40 % on each class (Fig. 3.2). For both these strength classes blended cement CEM II dominates the picture. For the very high strength class on the other hand pure Portland cement is dominating.

Looking further into the CEM II production figures (Fig. 3.3) it appears that limestone is the most important main constituent amounting to about half of the CEM II production independent of strength class. This is not surprising since limestone is available at almost any location where cement is being produced. The availability of slag and fly ash, on the other hand, is highly dependent on the energy strategy and on the type of industrial waste products being produced in the various regions of Europe.

<sup>k</sup> The European cement association [www.CEMBUREAU.be](http://www.CEMBUREAU.be)

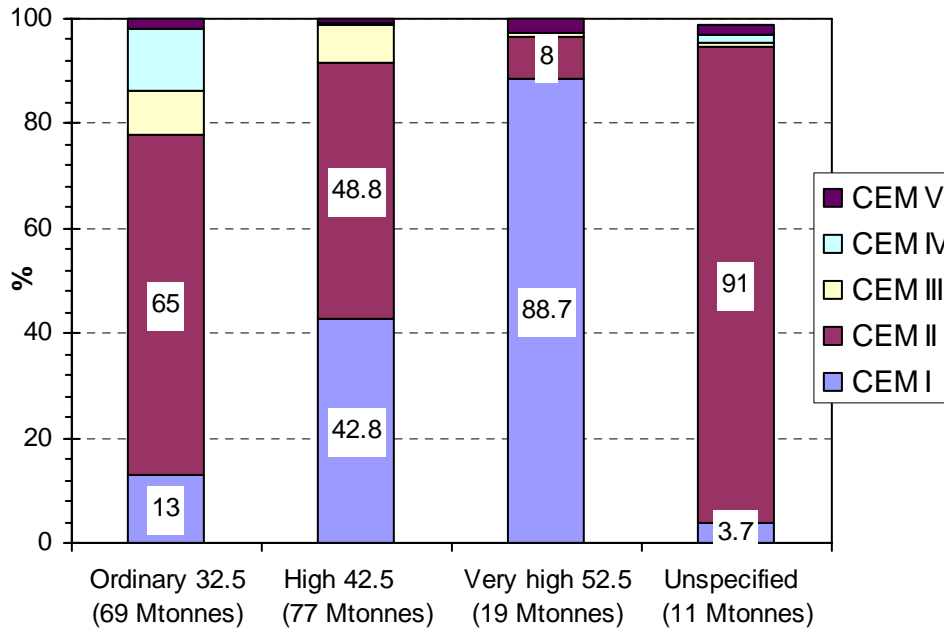


Figure 3.2 Cement production distributed on cement type and strength class. The numbers on the columns indicate the share of CEM I and CEM II within each strength class. The figure below each column shows the production of that particular strength class. Source: CEMBUREAU 2001 production figures.

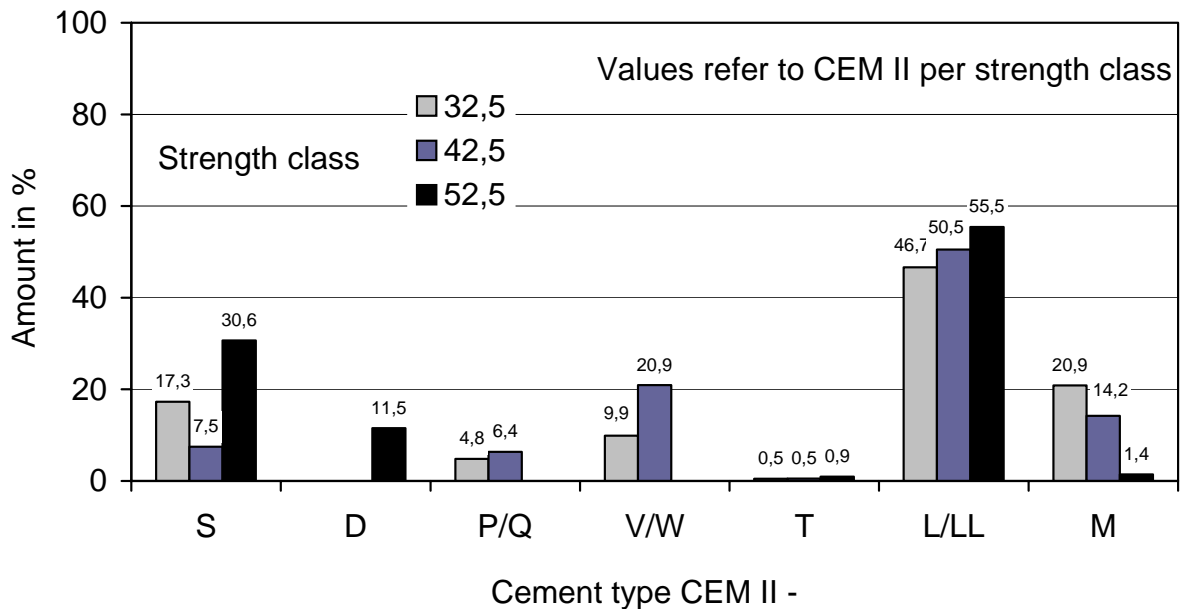


Figure 3.3 CEM II production figures distributed on strength classes for each main constituent. Total production is approximately 100 million tonnes. Source: CEMBUREAU 2002 production figures.

Figure 3.4 shows how pure Portland cement has been replaced with blended cements in some of the major European countries. In France and Italy blended cement has been dominating in ordinary and high strength classes since the early 1990ies. In Germany the trend is the same but the rate is much slower. This trend is expected to continue all over Europe and the outcome will be that only cement for the very high strength class is CEM I in the future.

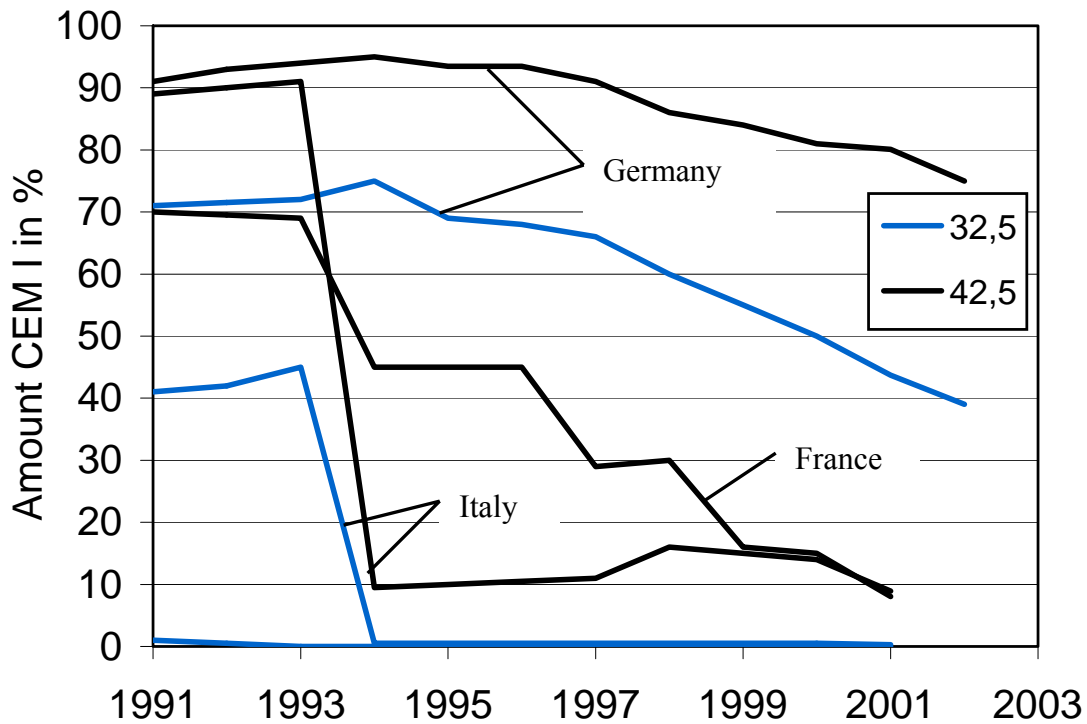


Figure 3.4 Development in CEM I production/use. Source: CEMBUREAU and VDZ.

Figure 3.5 shows the regional differences in the use of blended cement. However, these differences are mainly due to the fact that:

1. Several countries do not traditionally use blended cement but add supplementary cementitious materials to the concrete at the plant. This applies to England and Ireland where granulated blast furnace slag is used extensively or in Denmark where fly ash is being used extensively for ready mixed concrete.
2. NAD's from various countries allow the use of different cement types according to the durability demands in each country together with the availability of raw materials.

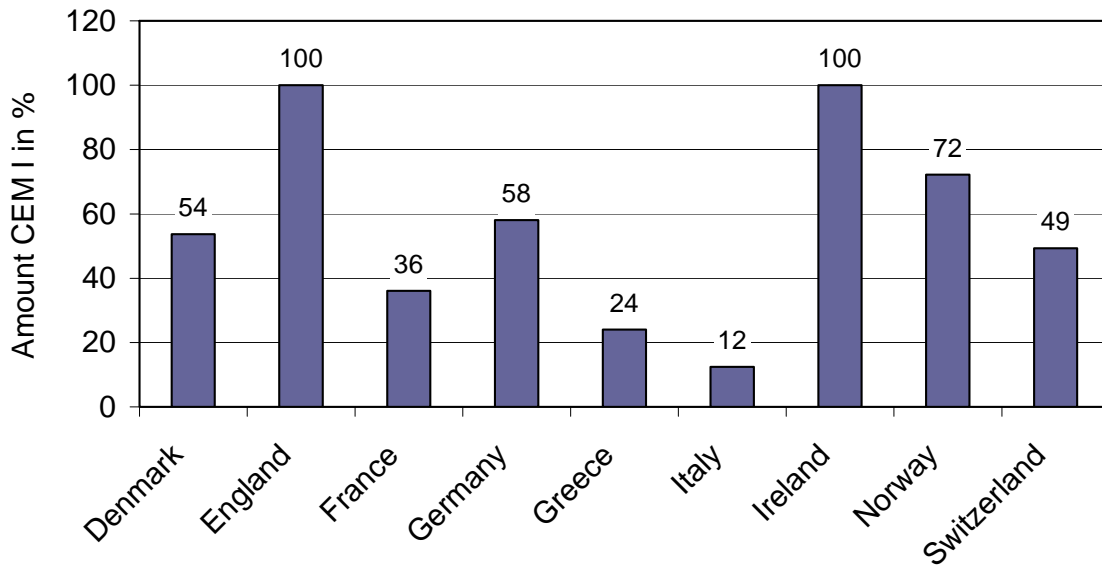


Figure 3.5 CEM I production figures distributed on countries related to total cement production per country. England and Ireland are estimated. Source: CEMBUREAU 2001 production figures.

### Environmental effect of blended cements

Generally it can be said that cement production is intensive in energy consumption as well as in its raw material demand. The raw material (lime) for cement production is available in huge amounts almost everywhere around the globe. Therefore, cement is typically a product manufactured and used locally based on regional mineral resources. However, cement manufacturers are typically multinational businesses operating in several countries.

Beside the energy needed to produce cement the calcination of lime into clinker particles produces large amounts of CO<sub>2</sub> – typically almost 1 kg CO<sub>2</sub> per kg clinker (Fig. 3.7). Therefore, reducing the clinker content of cement with other constituents directly influences the CO<sub>2</sub> emissions. This is of course under the assumption that concrete performance is not impaired by the use of reduced clinker content. Cluster 2 is working actively in documenting that blended cement may improve the performance over pure Portland cement. For instance the addition of limestone filler increases the workability of concrete given the same water-cement ratio. This is being used to produce self-compacting concrete. Furthermore, blended cement generally produces less heat of hydration, which may be an advantage in case of massive structures and hot climate.

Cluster 2 has performed a CO<sub>2</sub> calculation to document the reduced emissions from CEM II/B-S with 35 % slag and ordinary strength class. The production conditions are German with an average fuel consumption of 3.5 MJ/kg clinker, using hard coal as fuel. The conversion factor for electricity is 0.67 tonnes CO<sub>2</sub> per MWh. Under these assumptions CEM I is produced with 0.84 kg CO<sub>2</sub> per kg pure Portland cement (Fig. 3.7).

The reductions in CO<sub>2</sub> emissions are depicted in Fig. 3.6 for the blended slag cement. Drying and grinding of the slag requires a little amount of extra energy while the clinker substitution accounts for a significant reduction.

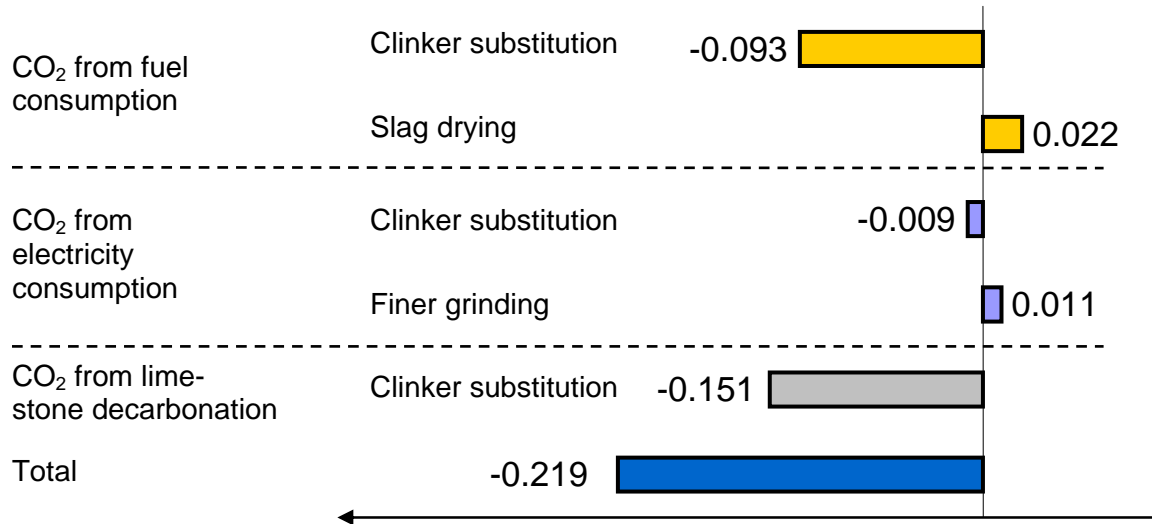


Figure 3.6 Reduction figures of CO<sub>2</sub> per weight unit cement (CEM II/B-S). Corresponding to ordinary strength class and under German production conditions.

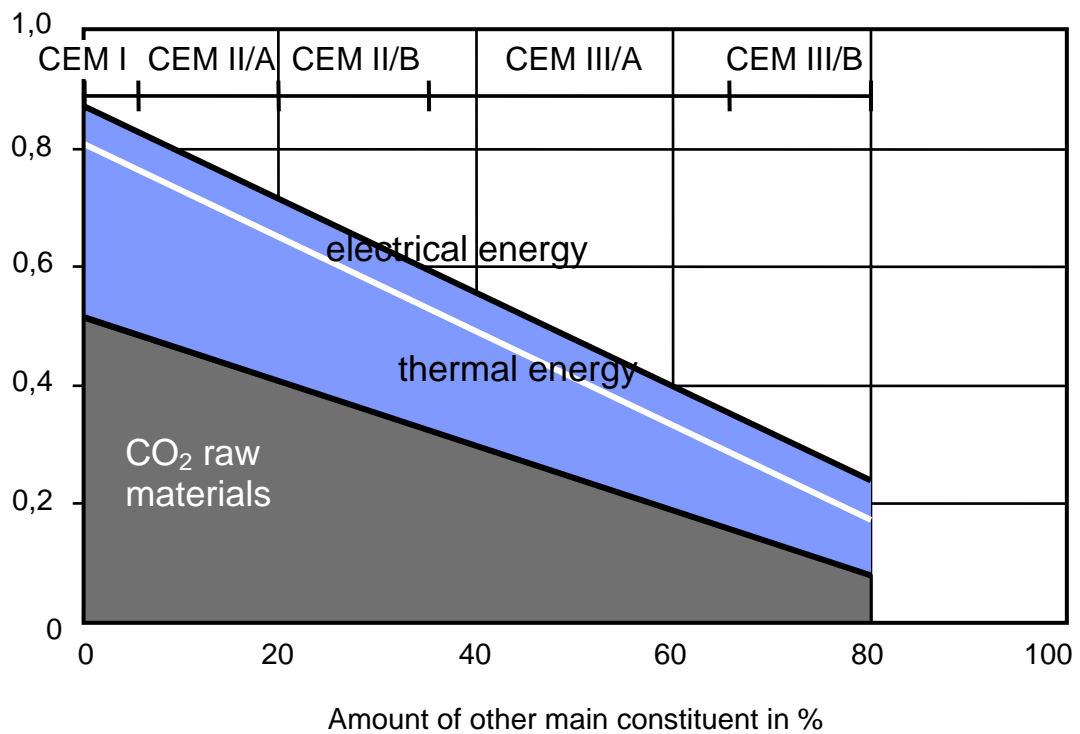


Figure 3.7 Emission of CO<sub>2</sub> per weight unit cement. Corresponding to ordinary strength class and under German production conditions.

### 3.3 National application rules

Production of concrete is governed by EN 206-1:2002 where it is stated that “*General suitability is established for cement conforming to EN 197-1*”. However, due to the huge differences in traditions, material availability and environmental exposure across Europe each member state has to adopt a National Application Document that states the conditions for that particular country.

EN 206-1 operates with a series of environmental exposure classes covering all combinations of environments for a concrete structure to function under. In Table 3.1 these exposure classes are summarised. Some classes are valid for one country while others are obviously useless. Exposure classes XC, XD and XS concern corrosion of reinforcement while XF and XA concern concrete degradation.

Table 3.1 Environmental exposure classes according to EN 206-1. Each exposure class is subdivided in a number of sub-classes to describe the severeness of the exposure.

Exposure class	Description	Remark
X0	No risk of corrosion or attack	Indoor dry conditions
XC	Risk of carbonation	4 sub-classes
XD	Risk of de-icing salts from other sources than sea water	3 sub-classes
XS	Risk of chloride exposure from sea water	3 sub-classes
XF	Risk of frost/thaw attack	4 sub-classes
XA	Risk of chemical attack	3 sub-classes

EN 206-1 includes an informative Annex F, combining the exposure classes with recommended values for concrete quality under the assumption that a concrete structure design life is 50 years. Furthermore, EN 206-1 is based on cement type CEM I, strength class 32.5.

EN 206-1 states that the requirements for each exposure class shall be specified in terms of:

- permitted types and classes of constituent materials;
- maximum water/cement ratio;
- minimum cement content;
- minimum concrete compressive strength class (optional);
- and minimum air-content of the concrete (if relevant).

Cluster 2 is co-working with CEN<sup>1</sup>, performing a comparison of NAD’s in the various member states. This work is taking place right now and therefore the following should be read keeping this in mind. Furthermore, co-operation is going on with Cluster 3, which is also represented in the CEN activities.

<sup>1</sup> Technical Committee 104/SC1

Figure 3.8 contains a comparison of minimum cement contents dictated in various NAD's. Combining these values with the allowed cement types the minimum clinker content is calculated. It is seen how most countries has adopted the recommended value of 300 kg cement per m<sup>3</sup> from EN 206-1. Furthermore, since all countries except Denmark allow CEM III/B with up to 80 % slags the minimum clinker content is about 20 % of 300 kg/m<sup>3</sup> = 60 kg/m<sup>3</sup>. However, in Denmark CEM II/B-V is allowed, giving a minimum clinker content of about 100 kg/m<sup>3</sup> based on a minimum cement content of only 150 kg/m<sup>3</sup>. This emphasises the fact that the rules differ significantly from country to country.

More comparisons should be made for instance on how the k-factors are applied across Europe.

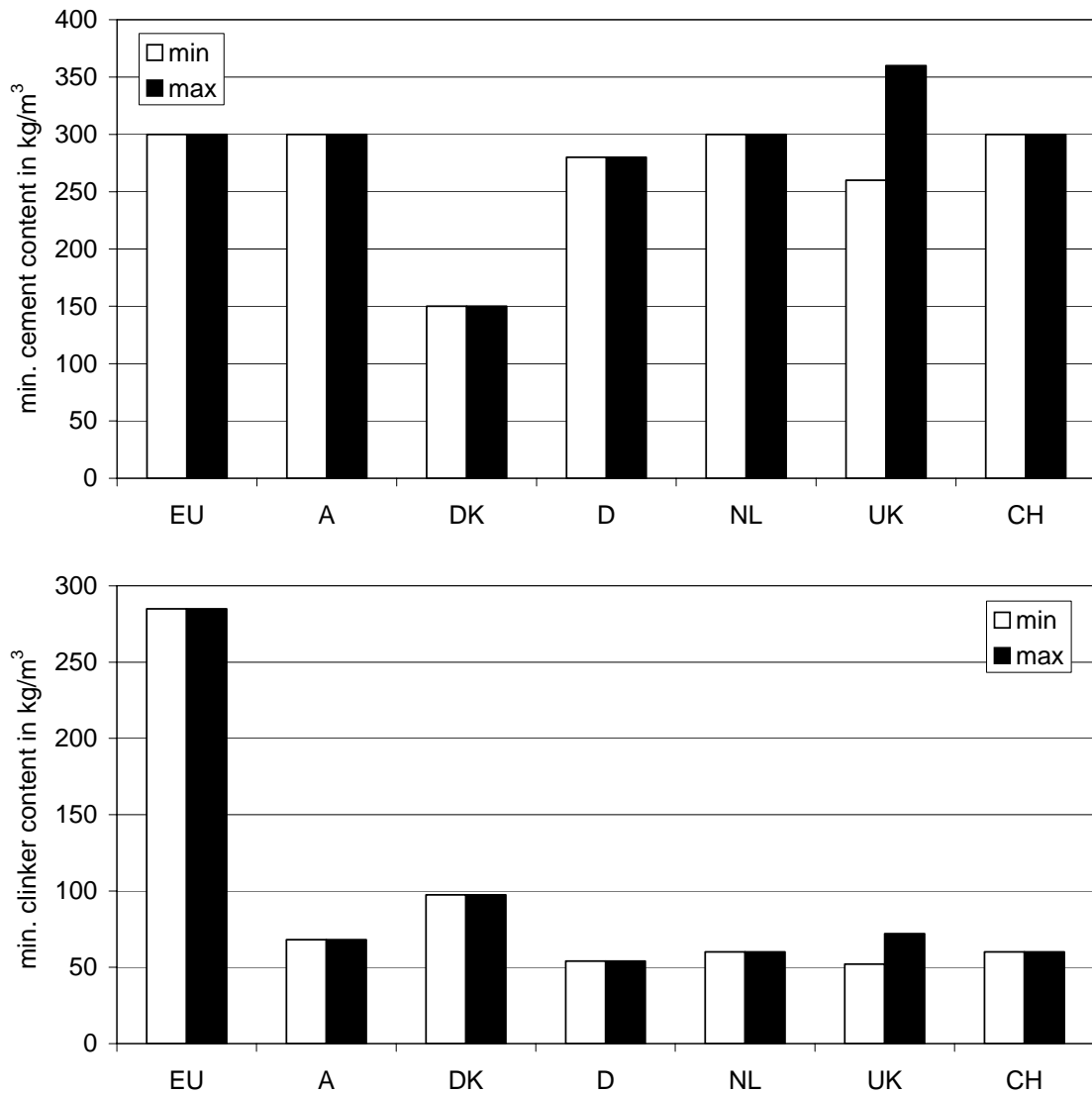


Figure 3.8 Comparison of NAD Annex F for various countries. EU denotes the recommended values in EN 206-1. Source: Cluster 2 presentation.

## 4 Cluster 3: Aggregate and Concrete Production

For various reasons aggregate and concrete production have been placed within the same cluster. Cluster 3 has produced a Baseline Report<sup>12</sup> which is taken as basis for this chapter. The reader is referred to this report for details together with an extensive list of references.

### 4.1 Scope

Environmental issues are treated regarding to the production of natural aggregates and conventional normal weight concrete. Hence, the results do not necessarily cover lightweight aggregate and concrete production, roller compacted concrete and other special concrete types.

In the Nordic network “Concrete for the Environment” completed in December 2003<sup>m</sup>, consensus was reached on the definition of a sustainable concrete structure:

*“An environmentally sustainable concrete structure is a structure that is constructed so the total environmental impact during the entire life cycle, incl. use of the structure, is reduced to a minimum. This means that the structure shall be designed and produced in a manner, which is tailor-made for the use, i.e. to the specified lifetime, loads, environmental impact, maintenance strategy, heating need etc. This shall be achieved by utilising the inherently environmentally beneficial properties of concrete, e.g. the high strength, good durability and the high thermal capacity. Furthermore, the concrete and its constituent shall be extracted and produced in an environmentally sound manner.”*

This definition considers the entire life cycle of a structure. The activities in ECO-SERVE Cluster 3 deals with the production phase only, i.e. until the material is ready to be built into a construction. However, the discussions of environmental issues should be seen in a holistic perspective, meaning that one has to take into consideration the entire life cycle when evaluating environmental issues and when comparing various solutions with respect to material choice and structural design.

The issue of reusing construction and demolition waste (C&DW) is also treated since it is an essential aspect when considering sustainability in the aggregate industry.

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<sup>m</sup> Funded by the Nordic Innovation Centre ([www.nordicinnovation.net](http://www.nordicinnovation.net))

### 4.2 Technologies for sustainable aggregate production

Aggregates<sup>n</sup> like sand and gravel have chiefly been quarried from natural resources, however an increasing amount is coming from crushed rock and the use of recycled material. Construction and demolition waste (C&DW) recovered during road repairs and building renovations are also increasing. There is a growing awareness that these waste materials should be recycled back into construction and thereby reducing the need for natural aggregates.

The sustainability issues of aggregate production have been on the agenda at a series of conferences over the past years. European societies are realizing the importance to balance the need for mineral raw materials against the need to protect the natural environment from unnecessary adverse impacts<sup>13</sup>. Many countries have expressed concerns about the sustainability of the aggregate resources, both in terms of tonnage remaining and also land-use issues. This is especially pronounced in regions facing a shortage of adequate local materials and also in regions with a high population density such as the Netherlands.

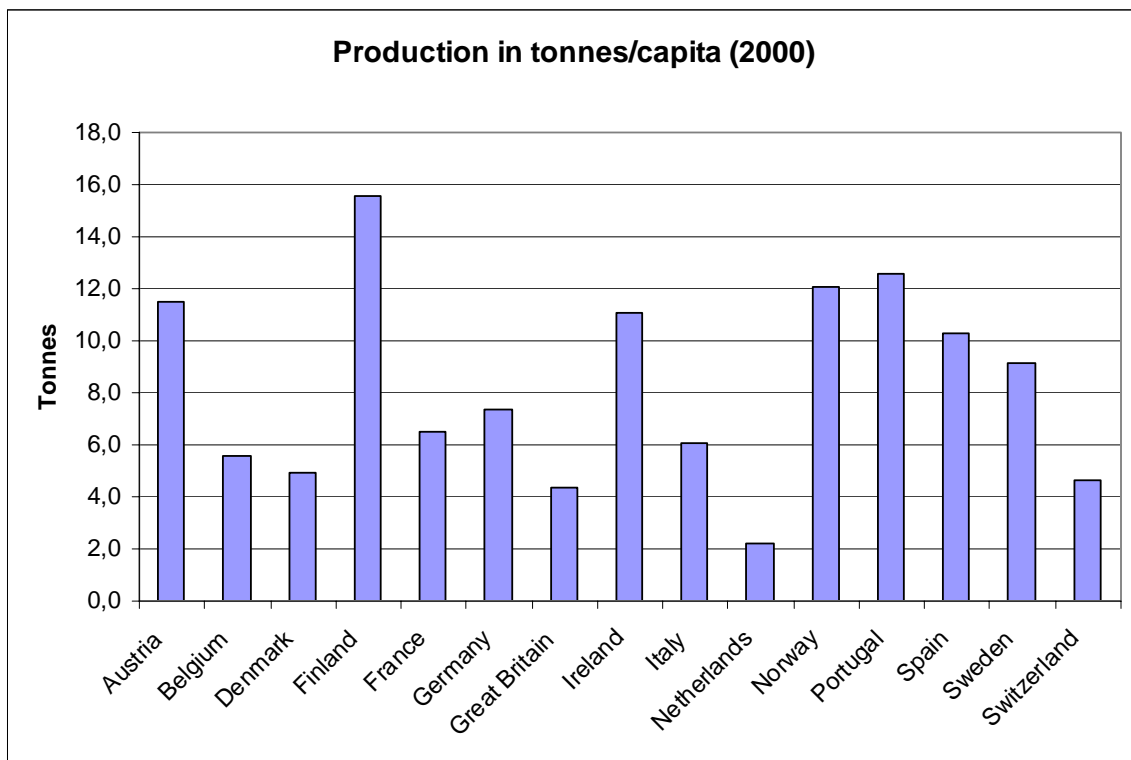


Figure 4.1 Production of Aggregates in tonnes/capita in European countries (Source: UEPG).

<sup>n</sup> The European standard for aggregates (EN 12620:2002) states: "Aggregate is a granular material used in construction. Aggregate may be natural, manufactured or recycled." The most common natural aggregates of mineral origin are sand, gravel and crushed rock.

The aggregate industry in the 15 European countries that are members of the European Aggregate Association, UEPG<sup>o</sup>, produced in the year 2000 some 2,620 million tonnes of sand, gravel and crushed rock, representing an EU average of 6.9 tonnes per capita. This total exceeds the total tonnage of all other minerals produced in the EU. Clearly, this is bound to have environmental impacts and it is our responsibility to optimise the use of this resource. The production tonnage differs significantly around Europe due to huge variations in mineralogical resources and availability of materials (Fig. 4.1). Furthermore, large import/export is taking place between neighbouring countries.

The industry has both economic and social impacts: the annual value of the raw material and processed products (aggregates) is 35,000 million € for these countries, and the industry directly employs 250,000 people.

The main sustainability issues concerning aggregate production may be boiled down to the following:

1. Depletion of mineral resources.
2. Land-use. Leaves the landscape changed after use. Recreational versus industrial conflicts. Noise and dust are problems both towards the external environment (neighbours) and the working environment.
3. High energy consumption due to transportation.
4. Mass balance and surplus materials (e.g. stone dust).

It may be said that, in some regard, the aggregate industry is facing an image problem all over Europe. New quarry applications are rejected on grounds of various environmental issues, and in some countries existing quarries only get a few years licence at a time. It is therefore safe to say that the aggregate industry is often unwanted in the eyes of the public. However, at the same time the society asks for new/upgraded infrastructure, which again increases the need for aggregates.

#### **4.2.1 Mineral resources**

With natural sand/gravel resources being rapidly depleted all over Europe, the needs of the construction industry will have to be met increasingly from crushed/manufactured aggregates. For instance in Norway, with a traditional abundance of glaciofluvial sand gravel, the last 20 years have seen a marked transition from sand/gravel to crushed rock in the market: while in the 1980ies 50-60 % of the production value in the aggregate sector could be ascribed to natural sand/gravel the corresponding figure today is 20 % and decreasing.

Several countries are currently applying resource taxation and/or regulations, to limit the exploitation of scarce sand/gravel resources. These economical instruments may be combined with land fill taxes on construction and demolition waste (C&DW) in order to promote the recycling of C&DW into construction and thereby saving natural resources.

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<sup>o</sup> <http://www.uepg.org>

The Dutch CUR recommendations were among the pioneering national guidelines on the subject, and in the early 1990ies a CEN TC 154 ad hoc committee was given the task to draft an amendment on recycled aggregates to the new European aggregate standards.

The main application for C&DW today is mostly in road constructions or bulk fill material. In Norway, Denmark, Finland, France and Iceland most of the C&DW is recycled into road constructions. In the UK and the Netherlands it is normal to recycle C&DW into both new concrete and road construction.

An extensive survey regarding (C&DW) was carried out by Symonds<sup>14</sup>. Information available in that report forms the basis for Table 4.1.

Country	Year of statistics (or estimate)	Concrete, brick, tiles (inert)	Other Core C&DW	Sub-total ('Core' C&DW)	Population millions (1997)	'Core' C&DW (kg/ person/yr)	Soil, stones etc.	Road planings (mainly asphalt)	Total
Germany	1994-96	45.0	14.0	59.0	82.0	720	215.0	26.0	300.0
UK	1996	n/a	n/a	30.0	58.9	509	29.5	(**)7.5	67.0
France	1990-92	15.6	8.0	23.6	58.4	404	n/a	n/a	n/a
Italy	1995-97	n/a	n/a	20.0	57.5	348	n/a	n/a	n/a
Spain	1997	n/a	n/a	(*)12.8	39.3	325	n/a	n/a	n/a
Netherlands	1996	10.5	0.7	11.2	15.6	718	6.3	(**)2.7	20.2
Belgium	1990-92	6.4	0.3	6.8	10.2	666	27.0	(**)0.9	34.7
Austria	1997	3.6	1.1	4.7	8.1	580	20.0	1.7 (**)	26.4
Portugal	1997	n/a	n/a	(*)3.2	9.9	325	n/a	n/a	n/a
Denmark	1996	1.8	0.8	2.7	5.3	509	7.7	(**)0.4	10.7
Greece	1997	1.8	n/a	1.8	10.5	172	n/a	n/a	n/a
Sweden	1996	1.1	0.6	1.7	8.8	193	1.5	(**)2.7	5.9
Finland	1997	0.5	0.8	1.3	5.1	255	8.0	(**)0.1	9.4
Ireland	1995-97	0.4	0.2	0.6	3.7	162	1.3	0.0	1.9
Luxembourg	1997	n/a	n/a	(*)0.3	0.4	700	n/a	n/a	n/a
Iceland	2000	0.11	0.06	0.17	0.29	600	3.5	0.03	

Table 4.1 Estimate of the quantity of C&DW in Europe (million tonnes).  
n/a: Information not available. (\*) Estimated. (\*\*) From an OECD-report.

Of the main conclusions of the Symonds-report is the fact (in the year 1999) that the amount of C&DW, which may be recycled with today's technology, is only about one fifth of the amount of primary aggregates used.

According to the Symonds report, 17 % of C&DW in Germany is recycled and 45 % in the UK. This proportion is 65 % in Germany and 80 % in the UK.

Landfill taxes are in effect in several countries together with mandatory recycling schemes<sup>15</sup>. Such schemes may include a general ban on land filling of certain materials and/or mandatory separation and sorting. According to OECD (2003)<sup>15</sup> ten European countries currently apply landfill taxes.

#### 4.2.2 Land use

Most people rely on the commodity of the infrastructure for everyday life, however, very few, want to live next to a quarry. Part of the problem is that public authorities in many countries do not have an over-all resource strategy, where the long term need for and supply of crucial materials is balanced against land-use and preservation issues. Incorporated in such a strategy should also be possibilities to use a quarry after it has been closed, making the value of the area increase, e.g. for housing, industry, recreation areas and lakes. Thus, the keyword is long-term planning, which should be performed in cooperation between authorities and the industry.

#### 4.2.3 Energy consumption

The energy issue is a very complicated one, owing to an assortment of energy types used and various geological settings. It involves the aggregate production as well as the transport and the final application of the aggregates.

Aggregate plants are either fixed or mobile; fixed plants normally use electricity whereas mobile units run on fossil fuel. With regard to efficiency, comparison of these two types of plants is difficult. The type of energy used also depends much on the geological setting: producing aggregates from crushed rock requires more energy for processing than excavating sand and gravel. The latter, however, use more energy for transportation within the quarry itself. In Denmark, for instance, the production relies heavily on wheel loaders.

The energy consumption per tonne of produced aggregates is relatively small compared to the energy consumption of other materials required for concrete production. Taking into account that the production of one m<sup>3</sup> of concrete typically requires about 2 tonnes of aggregates and 300 kg of cement the energy consumption associated with cement is still 20 times higher than that associated with aggregate production. Note that these figures do not include material transport to the concrete production plant.

In many situations the greatest energy impact in the aggregate sector is linked to the materials transport – from the quarry to the customer, an increasingly important issue as more and more densely populated areas are running out of local materials supply, and land use conflicts in these areas show a tendency not in favour of quarrying.

#### 4.2.4 Mass balance and surplus materials

One of the main challenges in aggregate production, especially when producing crushed aggregates from hard rock quarries, is to obtain a satisfactory “mass balance”. Any excess fraction that has to be kept on stock – or even worse – deposited, creates an economic as well as an environmental problem. Meeting a good mass balance is not only a question of proper production methods, but also a commitment of the buyers to use low-performance materials whenever it is possible/plausible. A consequence of good mass balance is the extended lifetime of the resource. The Norwegian experience is that if quarries are well planned and the production is end-use oriented, surplus material is rarely a problem. Ultimately, zero-waste production should be a goal within the aggregate industry.

The development in resource availability (chapter 2.1.1) strongly challenges the concept of mass balance. With a tendency in the market towards more fine crushed materials and a use of key size fractions, the percentage of e.g. minus 4 mm crushed sand from a hard rock quarry may be of the order of 30 %. At the same time, a technology of utilising such materials in e.g. concrete is not fully developed and implemented throughout Europe. A consequence is huge amounts of surplus, fine-grained materials. If e.g. 2,000 million tonnes of the total European aggregate production of 2,600 million tonnes are crushed hard rock materials, approximately 600 million tonnes will be in the size range < 4 mm – and probably at least half of this will have to be deposited, due to lack of application technology and market.

### **4.3 Technologies for sustainable concrete production**

Sustainability issues associated with concrete production is almost synonymous with cement production. It is generally recognised that cement producers bear the heaviest duty for making concrete more environmentally friendly. This is also the reason why sustainable production is the topic for two of the four clusters within ECO-serve.

However, sustainable concrete production is more than minimising the cement content, which is demonstrated in the Baseline Report<sup>12</sup> of Cluster 3.

Several other organisations has been working on this topic for the last decade or more. See for instance two recent *fib* reports<sup>16,17</sup> or visit the homepage of the British cement and concrete sector<sup>p</sup>. Also in the Netherlands a lot of work has been done to improve sustainability of the concrete sector. For instance the Netherlands Concrete Society published a state of the art on concrete<sup>18</sup> including a country-by-country listing of the most important environmental aspects of concrete production.

The production of concrete annually amounts to 1.5-3 tonne per capita in the industrialized world (Fig. 4.2), making the concrete industry including all of its suppliers a major player in the building sector. Thus, improving the sustainability of the concrete industry automatically will lead to significant improvements in the building sector as a whole.

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<sup>p</sup> [www.ConCemSus.info](http://www.ConCemSus.info) where a 8-page pdf report may be downloaded.

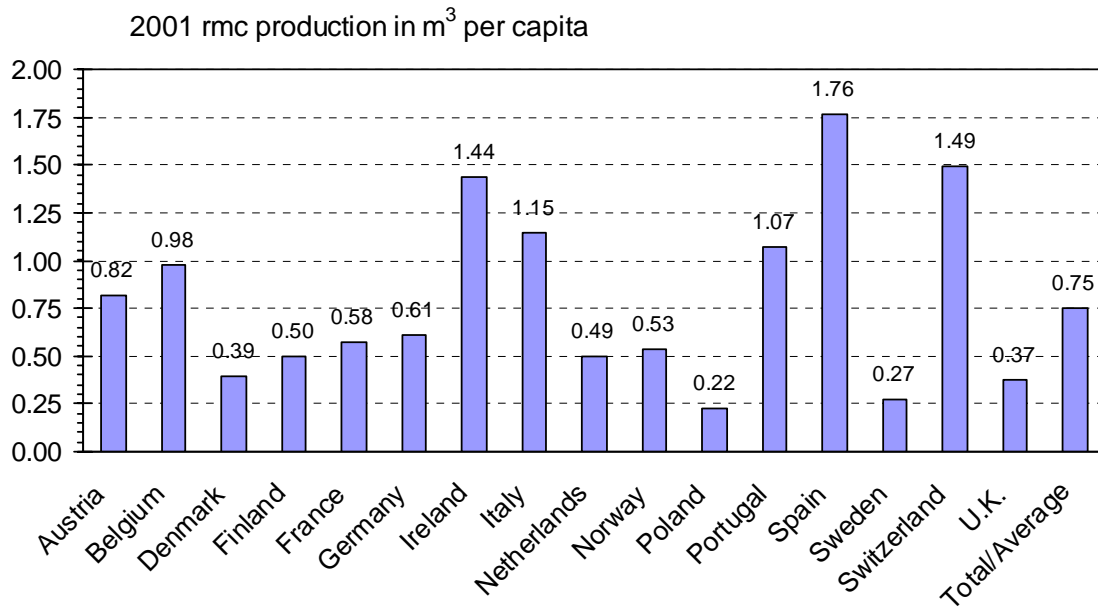


Figure 4.2 Annual ready-mixed concrete production per capita. Source: ERMCO 2001 statistics. More concrete production figures are found in Ref. 12.

Since concrete consists of a number of various constituents (Fig. 1.2) its environmental impact is a complex mechanism partly governed by the individual impacts from each of these constituents and partly governed by the combined effect of the constituents when they are mixed together. The aggregate part of concrete normally accounts for 70-75 % of its volume and therefore the environmental issues of aggregate production strongly influence concrete production. Furthermore, cement production is associated with large energy consumption and CO<sub>2</sub> emissions (Section 3.2.1). Furthermore, since concrete is most often reinforced by means of steel bars this material needs also be included in a total sustainability analysis.

In Figure 4.3 approximate CO<sub>2</sub> emissions are related to various production phases and materials of a prestressed hollow core slab based on Danish experiences.<sup>9</sup> The figures involve the emissions related to production of cement and prestressing steel plus emissions related to transportation and installation of slab together with demolition after completed service life. It can be seen that cement production contributes significant to the total CO<sub>2</sub> emission (about 55 %). However, if the carbonation of concrete (mainly taking place on concrete rubble after demolition) the CO<sub>2</sub> emissions released during calcination may be reclaimed. This contribution amounts to about 50 % of the CO<sub>2</sub> emissions during cement production, which may be counter balanced giving the negative contribution in Fig. 4.3.

<sup>9</sup> Calculations taken from TESCOP project.

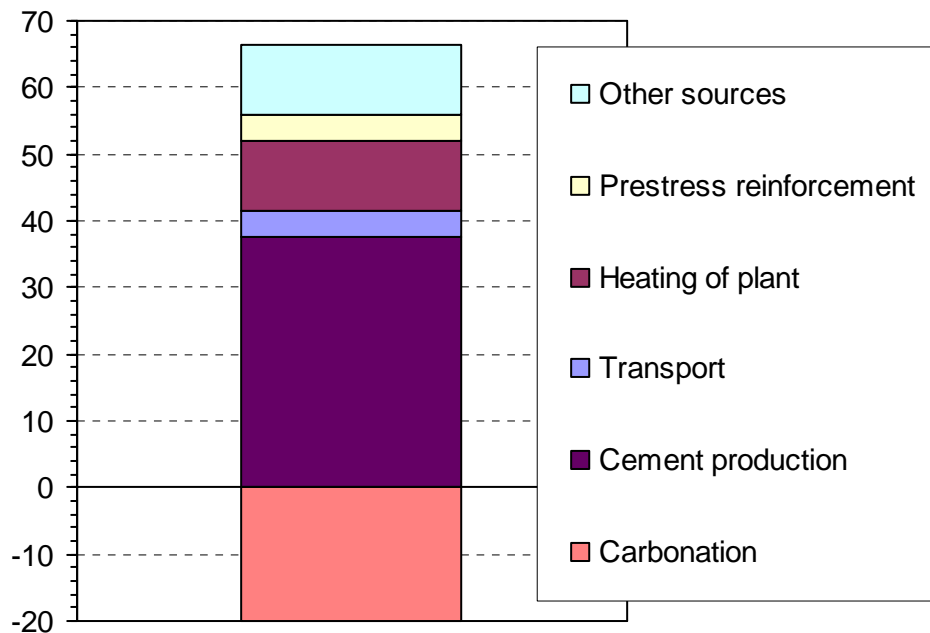


Figure 4.3 CO<sub>2</sub> emissions from production of prestressed hollow core slab.

The most important sustainability issues in concrete production are outlined below:

1. Emissions and energy consumption (CO<sub>2</sub>, SO<sub>2</sub>, embodied energy throughout production, transport and construction).
2. Waste products from concrete production (washing/mixing water, cement slurry, form oil, rejected concrete and excess production).
3. Working environment (noise, vibrations, dust, accidents)

Each of these issues is dealt with separately in the following sections.

#### 4.3.1 Reducing emissions by means of reducing clinker content

As it is demonstrated in Fig. 4.3 cement production is responsible for the major part of CO<sub>2</sub> emissions due to the calcination of clinker products. Therefore, reducing the clinker content in concrete is of major concern in order to improve the environmental performance of concrete. Many different sources estimate that approximately 1 kg of CO<sub>2</sub> is emitted to the atmosphere for each kg of cement produced<sup>19</sup>. This is of course very much dependent on production methods and local conditions but it still underlines the fact that reducing clinker content in cement and or the cement content in concrete improve the environmental profile of concrete. These issues are dealt with in more detail in Chapters 2 and 3 of this report.

When evaluating the CO<sub>2</sub> emission from concrete products seen in a life cycle perspective it shall be mentioned that the previous calculations and life cycle assessments do not take into account the fact that concrete actually consume CO<sub>2</sub> during its service

life and after demolition due to carbonation of cement paste. A Nordic project<sup>r</sup> is looking into this area in order to find out to which degree this effect should be included in LCA-calculations and to develop guidelines for including carbonation in calculations.

There are several ways to reduce the clinker content. The most popular being:

- Blending cement with supplementary cementitious materials such as fly ash, silica fume, slag, limestone etc. Blending may take place by the cement manufacturer and the product is denoted blended cement (CEM II – V)<sup>s</sup>. Or it may take place at the concrete plant.
- Optimising the concrete mix design, so that its performance fulfils the specifications with the lowest possible clinker content in the concrete.

The preferred method depends strongly on local traditions, availability of materials, practical experience, material prices and the specifications given in EN 206-1. In Denmark for instance almost all ready mix concrete contains pure Portland cement (CEM I) plus fly ash and microsilica mixed at the ready mix plant while most of the precast industry uses blended cement (CEM II). Note that each country has a national application document implementing EN 206-1 to the specific conditions that rules in that particular country. Reference is made to the work carried out in Cluster 2 where the specifications across Europe has been evaluated and reported. Further details are found in Chapter 3.

### Use of supplementary materials

In the following a number of different materials are briefly described. These materials are being used or can be used as a supplement to the binder matrix in concrete: in most cases they allow to lower the cement content and in some cases to improve specific concrete properties. Some of the materials mentioned have pozzolanic effect in concrete and thereby contribute to the hardening of the concrete, while others are inert.

The most common supplementary materials are fly ash (FA), micro silica fume (SF) and granulated blast furnace slags (GBFS). These materials are basically industrial waste products that have been refined into beneficial well-proven supplementary materials.

FA and SF are pozzolanas contributing to development of the concrete properties (mechanical and durability properties). Their contribution is taken into account by using the k-value concept.<sup>t</sup> However, the k-values differ from one country to another, which is reflected in the different National Application Documents. The k-value has a large influence on the pricing of a supplementary material. For instance, silica fume is often used with k=2, meaning that the price of SF could in theory be twice that of cement.

FA has been used in concrete for half a century and out of an annual European production of 40 million tonnes half is used in the construction industry<sup>u</sup>. The normal substitution

<sup>r</sup> “CO<sub>2</sub> uptake during the concrete life cycle” funded by the Nordic Innovation Centre.

<sup>s</sup> Cement types I – V defined in EN 197-1:2001

<sup>t</sup> k = 1 means that 1 kg of supplementary material may substitute 1 kg cement in the water to cement ratio.

<sup>u</sup> 2001 figures according to ECOBA (European Coal Combustion Products Association)

degree is 10-20 % (relative to cement weight) but experiences show that up to 50 % of the cement may be replaced with FA. The use of FA varies significantly from country to country. For instance FA is widely used in Denmark but not at all in Sweden. In Norway FA is used only to produce blended cement.

SF has been used extensively for the last two decades. The current annual world production of silica fume is been estimated between 0.5 and 1.0 million tonnes<sup>20</sup>, i.e. the availability of silica fume is very limited compared to other types of supplementary materials. Therefore, SF is only expected to have a limited effect as a clinker reducing supplementary material.

GBFS has been used as a partial replacement of Portland cement for at least a century. The annual production of blast furnace slag in Europe in 1999/2000 is about 56 million tonnes of which 60 % are granulated for use in blended cement or as supplementary material in concrete. Germany, Belgium and the Netherlands have a utilisation degree of GBFS above 80 %.

Other supplementary materials count limestone filler being used for cement and concrete production. It has been found to increase workability and early strength, as well as to reduce the required compaction energy. Nowadays limestone filler is of particular interest for Self Compacting Concrete (SCC) where the need for fine particles to obtain adequate flow properties is essential.

In France the fly ash sources are limited due to nuclear power plants while very good limestone sources exist. Therefore, limestone filler is used to a large extent in concrete. Also the Netherlands, the UK, Italy and Spain use limestone filler for concrete applications and for production of blended cements.

Wastes from other industries are also considered as supplementary materials for concrete. In Denmark sewage sludge incineration ash has been investigated<sup>v</sup> and found plausible for concrete applications. In Sweden ashes from combustion of bio fuel are used as a supplementary material for concrete in the lowest exposure classes.

Metakaolin is a highly reactive pozzolan formed by the calcination of kaolinite (China clay). Considerable CO<sub>2</sub>-emission is associated with the production of metakaolin. This considered and also bearing in mind that metakaolin is rather expensive and that only a limited production is taking place it seems unlikely that metakaolin will be a source of positive environmental impact in connection with concrete production.

### **Optimising mix design**

There exists many design models for optimising the mix design of concrete. The purpose of these models is primarily to be able to design concrete with specific properties and at the same time reducing its cost. In most countries the expensive concrete constituent is cement. So minimising the concrete cost in most cases also minimises its environmental

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<sup>v</sup> Centre for Green Concrete, [www.greenconcrete.dk](http://www.greenconcrete.dk)

impact. However, in some regions the priciest part of concrete may be the aggregate and the optimisation gets complicated and not so straightforward.

One way of optimising concrete composition is by optimising the aggregate composition in order to obtain dense packing of the aggregate particles minimising the need for binder and thereby for cement (e.g. the Danish modification of Linear Packing Density Model by Glavind 1993)<sup>21</sup>. Other models take into account all solid particles when calculating the optimal composition<sup>22,23</sup> (Compressive Packing Model).

Another way of reducing cement content in concrete is by a careful use of admixtures. The development of normal and high range water reducing admixtures has reduced the water demand in concrete significantly and thereby also the quantity of cement. Admixtures have become normal constituents of concrete all across Europe due to their obvious benefits for the manufacturers of concrete. Furthermore, new types are being developed constantly ensuring that the price is kept reasonable.

#### **4.3.2 Recycling of waste products in concrete**

For concrete production the most relevant waste products to consider for reuse may stem from:

- Recovered aggregate washed out from fresh concrete (rejected batches, excess production) and reused as concrete aggregates.
- Washing water and water from saw cutting cleared from slurry and reused as mixing water or washing water.
- Recycled aggregate from construction and demolition waste (C&DW), i.e. hardened concrete rubble being crushed. Alternatively recycled aggregate may be produced entirely from rejected concrete coming from ready mix or precast plants.

#### **Reuse of recovered aggregates and water**

During concrete production large amounts of water is used to wash mixing equipment, trucks and formwork. Washing water contains a certain amount of cement paste (slurry) and residuals from form oil that must be separated in a sedimentation basin before reusing the water in the making of new concrete. It is also possible to collect and reuse rainwater from rooftops and pavements and add this to the sedimentation basin.

The technology for reusing water in concrete production is well-known and according to EN 206-1 it is possible. Furthermore, the technology is being widely used across Europe and that whenever a concrete plant is upgrading its production equipment water recycling is included in the considerations.

Similarly it is possibly to recover aggregates from fresh concrete and recycle it into new concrete. However, it seems that the preferred way to dispose reject concrete is to let it harden and crush it for road building purposes.

## Recycled aggregates

The most comprehensive collection of research and knowledge on the subject has been collected in the auspices of RILEM through several technical committees and a series of symposia. The RILEM work is summed up in an extensive state-of-the-art-report<sup>24</sup>.

Several European countries have implemented national standards and/or recommendations – much on the basis of the RILEM committees – covering production and application of the use of recycled aggregate in concrete and road construction. This applies to Austria, Denmark, Germany, the Netherlands, Norway, UK and Ireland.

From the literature<sup>24</sup> there seems to be a common agreement that the main technical problems facing further exploitation of recycled aggregate for concrete production are:

- Production aspects associated with the increased water absorption for recycled aggregate. This is particularly the case for the sand fraction.
- Slightly lower performance of recycled aggregate concrete. Depending on the degree of substitution and whether both coarse and fine aggregates are substituted.

It seems that most of the recommendations that exist are based strongly on the RILEM specifications published in 1994<sup>25</sup>. Here recycled aggregates for concrete are basically categorised into 3 types:

- I. Primarily produced from masonry rubble.
- II. Primarily produced from concrete rubble.
- III. Mix with minimum 80 % natural aggregates, maximum 10 % of type I and the remaining part of type II.

When using recycled aggregates of type III where only a part of the natural aggregates are substituted it is assumed that the mechanical properties are unchanged from those of a conventional concrete based on natural aggregates. When a full substitution is performed strength, stiffness, creep and shrinkage properties are expected to change, which needs to be taken into account in the structural design.

Typically it is recommended that only the coarse fraction be substituted by recycled aggregates. Furthermore, the specifications set limits for the amounts of foreign materials in the recycled aggregates.

At present the economical reasons for applying recycled aggregate into concrete production as compared to e.g. road construction, are limited in most European countries. One important economical issue is the storage facilities at a concrete plant. If new materials are added to the production the storage facilities need to be updated and extended. Another important issue is the availability and the transport distances. It seems most appropriate that C&DW is crushed and used locally and therefore a stable supply may only be maintained around major cities.

In the Netherlands, a requirement for a minimum content of recycled aggregates in new concrete has been applied in some cities, first of all with an environmental argument, but

also due to the supply situation of primary aggregates. In Norway, use of recycled concrete as aggregate has proved successful at precast concrete plants, which can recycle their own concrete waste from hollow core production instead of transporting them to a land fill.

### 4.3.3 Working environment and use of SCC

The concrete industry is traditionally seen as a dirty and dangerous place to work. However, lately more focus has been put on the concept of self-compacting concrete (SCC) that needs not to be vibrated or compacted mechanically in order to flow into the formwork, embedding inserts and rebars. This enables the contractors to omit a costly and time-consuming work process and thereby, increase their productivity. Furthermore, vibration is a noisy and wearing work operation that is having a large impact on the working environment due to the physical impact on concrete workers.

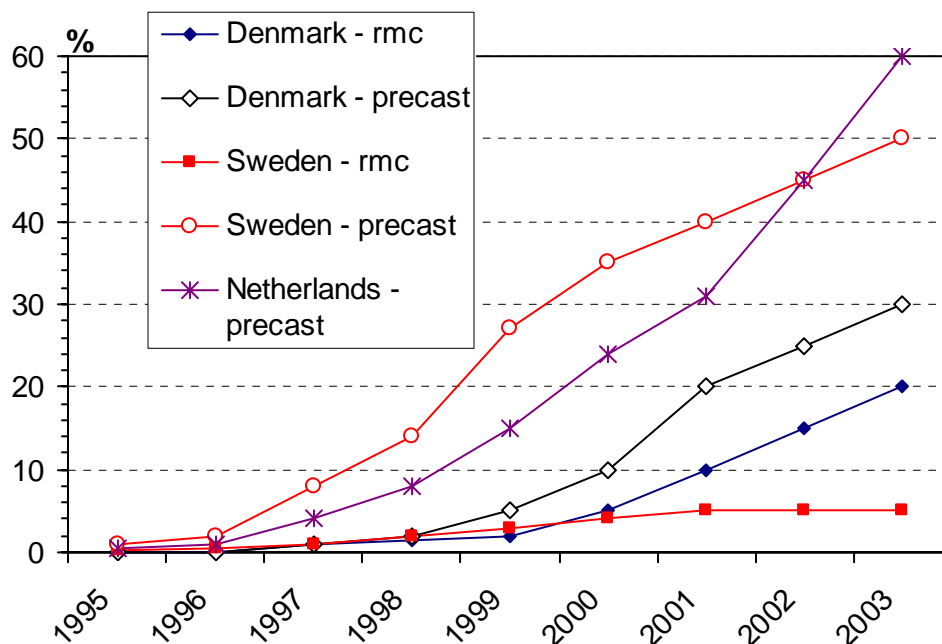


Figure 3.11 Trends for the application of SCC in ready-mixed concrete and precast concrete elements. The data are estimates collected from personal contacts by Danish Technological Institute.

Concrete vibration and compaction causes hearing damages as well as increasing the risk of Raynaud’s syndrome<sup>w</sup>. Therefore, several national projects have looked into the possibilities of SCC during the last decade. Figure 3.11 shows the trend in SCC-application within the past decade. The use of SCC seems to be growing mainly for precast concrete production where Sweden and the Netherlands are leading the way. In Japan – the birthplace of SCC – the use of SCC is still below 1 % of the total concrete production. A reason for this is that many practical problems still exists regarding robust

<sup>w</sup> Circulatory disorder that affects hands and feet with numbness due to insufficient blood supply.

mix design and finishing techniques. Furthermore, the use of advanced chemical admixtures still makes SCC rather expensive. When these problems are overcome it is expected that the application of SCC will increase significantly.

## 5 Cluster 4: Pavements

### 5.1 Scope

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

The central goal in cluster 4 is:

*To select the most suitable approach for design of low strength cementitious base course layers (in order to minimise binder consumption and to increase the use of local aggregates).*

Indicators (Table 5.1) are selected for giving insight into two topics:

- Binder consumption
- Extent of the use of local aggregates.

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

Table 5.1: Selected indicators for pavements.

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

### Current status

At the moment no public studies are known concerning the indicators mentioned in table 5.1. Important questions have to be assessed and answered, such as:

- How does the CO<sub>2</sub> emissions change if the binder in the pavement construction is cement instead of bitumen?' and
- What is the impact on the costs if locally extracted aggregates are used instead of crushed stone from Norway?

## 5.2 Tool

To be able to determine the sustainability through these indicators and in order to answer the previous questions an Excel tool is under development. With this tool different kinds of pavements can be designed. The user of the tool has to answer a short list of questions concerning the life cycle of the pavement. Answering these questions results in an overview of the indicators (Table 5.1). The general outline of the Excel tool is described in the following.

The Excel application is a flexible and dynamic tool that can be filled out by a producer of pavements. The tool includes the possibility of comparing two variants and the choice between asphalt, concrete or a combination of both. In this chapter the input parameters and the release output of the tool is briefly described.

### 5.2.1 Input parameters

To be able to measure and to express the indicators, they will be related to a so-called functional unit. The first step in the tool is to choose the functional unit. The functional unit consists of a unity aspect ( $\text{m}^2$  or  $\text{km}$ ) and a time aspect (the life span of the pavement)

An example of a functional unit is  $1 \text{ m}^2$  of 'Eco-Serve' pavement in Europe with a life span of 60 years.

The following step is to fill in variables (Table 5.2) for each phase of the life cycle. The life cycle of the pavement construction consists of 6 phases:

1. Extraction and transport of raw materials;
2. Production of asphalt from raw materials;
3. Application;
4. Maintenance;
5. Disposal;
6. Recycling

For each variable the matching  $\text{kg CO}_2$  emission and, if relevant, the matching tonkm is given. The costs (€) has to be filled in by the user according to the conditions he/she is producing under. When all the variables are filled in they are summed up and converted into the functional unit. Figure 5.1 gives an example of the input screen.

Table 5.2: Variables to be filled in for the different life cycle phases.

<b>Phase 1: Extraction and transport of raw materials</b>	
Questions:	What is the typical composition of the asphalt top layer (kg/ton)?
	What is the typical composition of the second layer (kg/ton)?
	What is the typical composition of the third asphalt layer (kg/ton)?
	What is the medium vehicle and the transport distance to the asphalt plant for each of the raw materials?
<b>Phase 2: Production of asphalt from raw materials</b>	
Questions:	How much energy is used for the production of 1 ton of the asphalt top layer in the asphalt plant (energy used for heating of minerals, evaporating of water etc...)?
	What is the transport distance of the mixed asphalt to a asphalt plant where the mixed asphalt is further processed to a prefab asphalt layer.
	How much energy is used for the production of the prefab asphalt layer? (mechanical process)
	How much energy is used for the production of 1 ton of the second layer?
	How much energy is used for the production of 1 ton of the third layer?
	What is the transport distance of the asphalt from the asphalt plant to location?
<b>Phase 3: Application</b>	
Questions:	How much energy is used for the application of the first layer?
	How much energy is used for the application of the second layer?
	How much energy is used for the application of the third layer?
<b>Phase 4: Maintenance</b>	
Questions:	How much energy is used for milling?
	How much energy is used for sealing?
<b>Phase 5: Disposal</b>	
Question:	How much energy is used for disposal?
<b>Phase 6: Recycling</b>	
Questions:	What is the transport distance to the crusher?
	How much energy is used for processing?

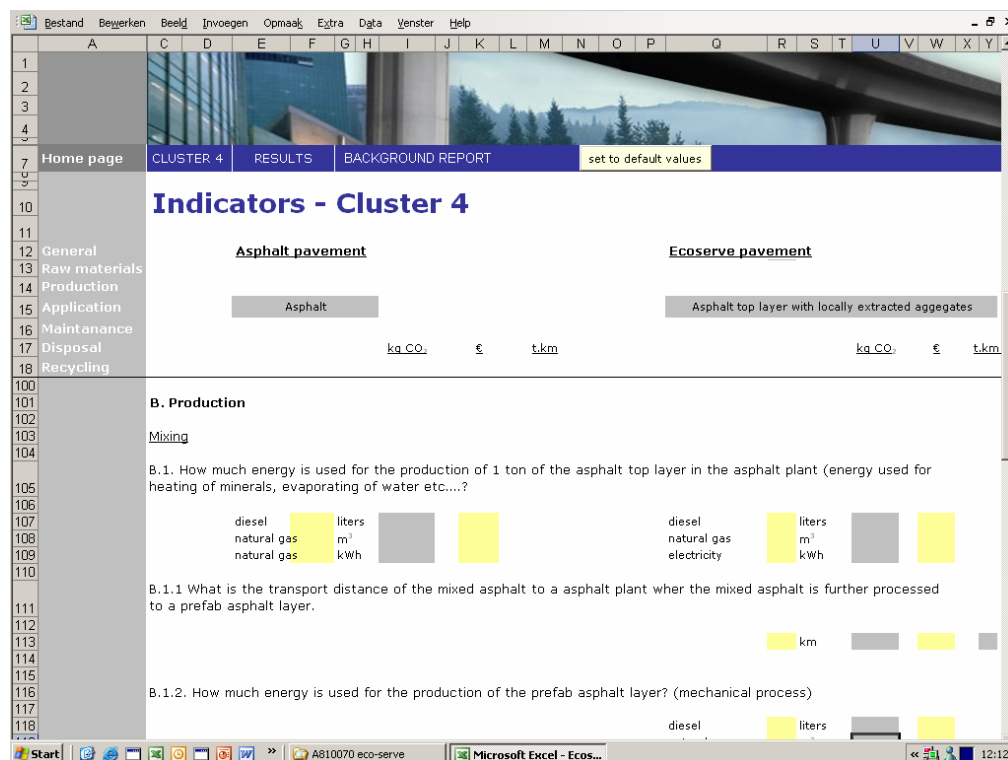


Figure 5.1 Screen dump from Excel tool.

### 5.2.2 Output

The results are given for the whole life cycle of the chosen scenarios. An example is given in Fig. 5.2.

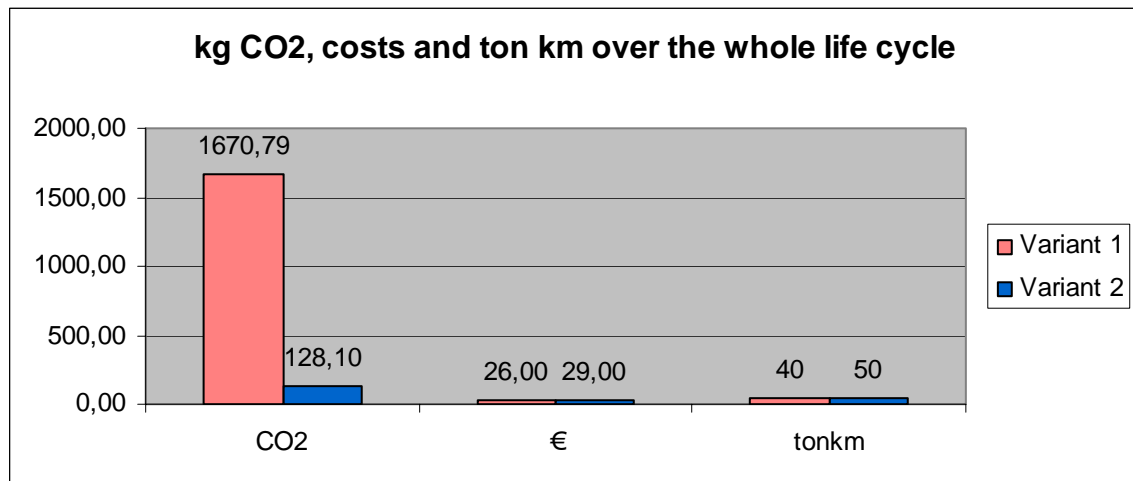


Figure 5.2 Indicative example of the kg CO<sub>2</sub>, the costs and the number of tonkm over the whole life cycle for two pavement scenarios.

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