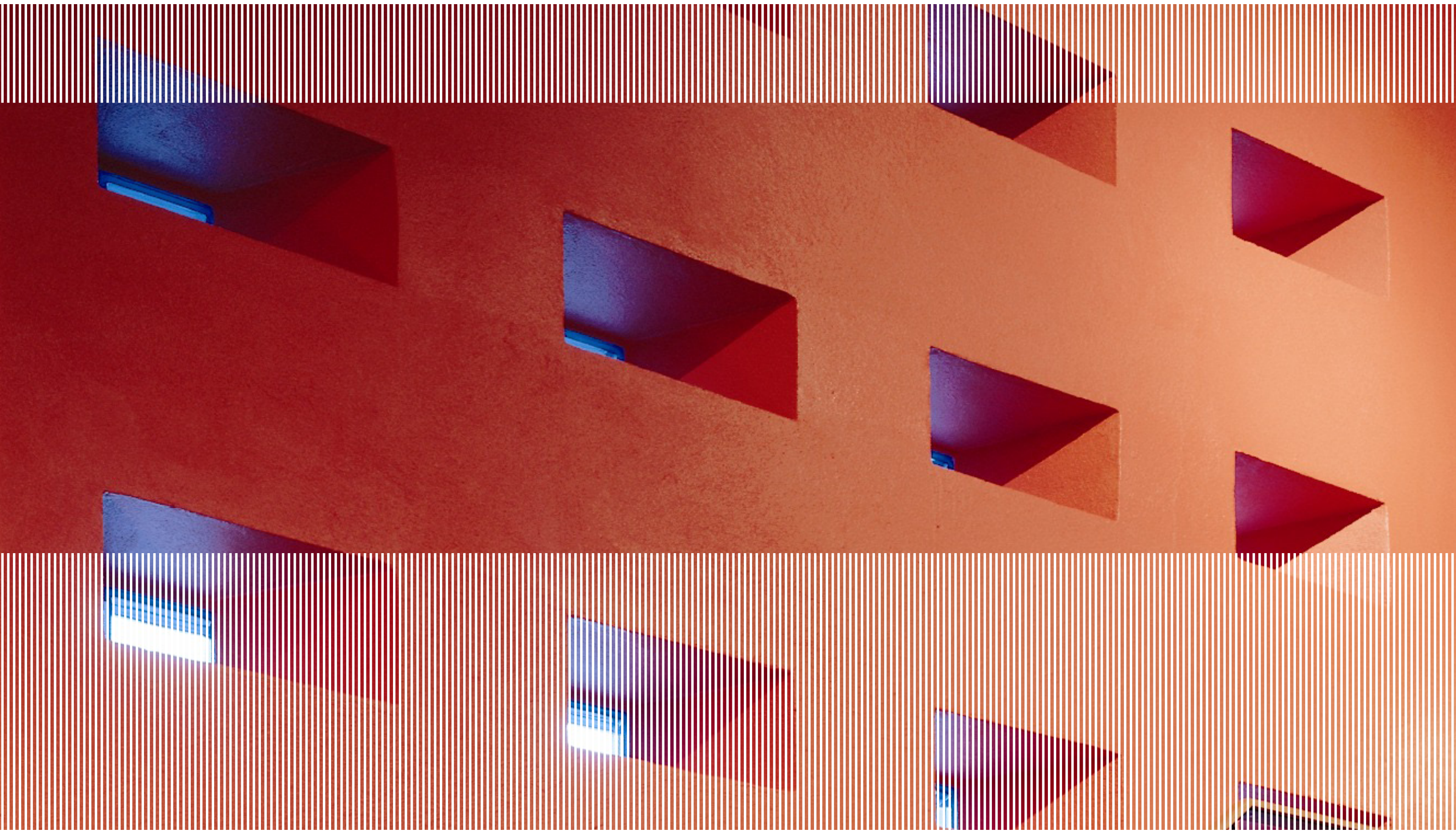
**SINTEF Building and Infrastructure** Thale Eng Kalbakk

# LCA on case study – concrete

## COIN Project report 36 – 2011



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FA 1 Environmentally friendly concrete

SP  Insulating and energy preserving concrete

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# Preface

This study has been carried out within COIN, - Concrete Innovation Centre - one of presently 14 Centres for Research based Innovation (CRI), which is initiated by the Research Council of Norway. The main objective for the CRIs is to enhance the innovative capability of the business sector by focusing on long-term research based on forging close alliances between research-intensive enterprises and prominent research groups.

The vision of COIN is creation of more attractive concrete buildings and constructions. Attractiveness implies aesthetics, functionality, sustainability, energy efficiency, indoor climate, industrialized construction, improved work environment, and cost efficiency during the whole service life. The primary goal is to fulfil this vision by bringing the development a major leap forward by more fundamental understanding of the mechanisms in order to develop advanced materials, efficient construction techniques and new design concepts combined with more environmentally friendly material production.

The corporate partners are leading multinational companies in the cement and building industry and the aim of COIN is to increase their value creation and strengthen their research activities in Norway. Our over-all ambition is to establish COIN as the display window for concrete innovation in Europe.

About 25 researchers from SINTEF (host), the Norwegian University of Science and Technology - NTNU (research partner) and industry partners, 15 - 20 PhD-students, 5 - 10 MSc-students every year and a number of international guest researchers, work on presently eight projects in three focus areas:

- Environmentally friendly concrete
- Economically competitive construction
- Aesthetic and technical performance

COIN has presently a budget of NOK 200 mill over 8 years (from 2007), and is financed by the Research Council of Norway (approx. 40 %), industrial partners (approx 45 %) and by SINTEF Building and Infrastructure and NTNU (in all approx 15 %).

For more information, see www.coinweb.no

Tor Arne Hammer
Centre Manager

## Summary

The aim of this study, using LCA, is to
1) Assess CO2 emissions and embedded energy of a passive house roof construction,
and
2) Identify the concrete with the lowest emissions and energy use

The goal of this analysis was to find out, by applying the LCA methodology, the embedded energy and GHG emissions of 1 m2 concrete roof. Further focus has been to look at consequences attached to the use of different types of cement in the concrete. The three different types of cement analysed is Portland-cement taken from the Ecoinvent database, Standard cement from Norcem and Low Carbon cement from Norcem. The results show that concrete based on the low carbon concrete has the lowest embedded energy and GHG emissions.

Kari Sørnes and Torhildur Kristjansdottir at SINTEF have contributed to the work presented in this report through the VISES(...) project.

In COIN 2011 we have limited the study to a cradle-to-gate study. Maintenance, service life and end of life will be treated in COIN 2012.

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# 1 Introduction

The main goal of COIN is to develop more attractive buildings and constructions from concrete. There are 3 focus areas of specific interest to this project:

1) Developing binders with low GHG emission and energy consumption
2) Utilizing concrete in low energy buildings, reforming the insulation properties of concrete with nanoparticles
3) Service life of concrete constructions, technical performance

A case study was carried through using LCA to assess the GHG emissions and embodied energy of a passive house roof construction made of concrete. Further, three cement types were chosen in order to identify the concrete with the lowest environmental load. The cement types chosen are Portland cement from EcoInvent, Low carbon cement from Norcem and standard cement from Norcem. Data for the low carbon cement and standard cement from Norcem is taken from Environmental product declarations (EPDs) on these specific products which are official available on the web (EPD-Norge 2011).

A short literature review shows that the scope of environmental analyses for construction materials is decisive for which results are achieved. This means that LCAs for different materials cannot uncritically be compared.

Summarized is the aim of this study to:

1) Learn about the different aspects of using the LCA methodology:
    a. The challenges of limiting the analysis in the goal and scope
    b. The challenges of the inventory analysis and data quality
2) Increase knowledge using the LCA-tool SimaPro
3) Use the LCA methodology to assess the environmental load of a passive house roof construction
4) Identify the concrete with the lowest GHG emissions and embodied energy

## 1.1 Background

The global cement industry produces approximately 2.6 billion tonnes of cement annually and the most important user application is in the production of concrete which usually has a cement content of 10-15%. In general, the $CO_2$ released from cement production is 50% from the calcination process, 40% from the fuel and 10% from the electricity consumption and transportation needs. Globally, the cement industry accounts for 5-8 % of the total anthropogenic $CO_2$ emission.

Literature studies performed at Østfoldforskning states that the environmental loads and energy consumption during a buildings operating life, maintenance processes and disposal (FDVUS) exceeds the emissions from the production phase. However, the load from the production phase will have a greater impact for low energy consumption-building (Rønning et al, 2011)

## 1.2 Related projects within SINTEF Building and Infrastructure

This report has benefited from three other projects in SINTEF Byggforsk related to the cement industry.

The first project is called VISES I (Verify and Improve SINTEFs Expertise in Sustainability I) in which he aim is to increase the knowledge within the field of life cycle assessments (LCA) at SINTEF Building and Infrastructure. For this project, the same case study is used.

The second important project is connected to the waste scenario and is executed in cooperation with Klima- og Forurensningsetaten (KLIF). The goal is to determine the leaching of toxic metals and PCB from demolished concrete constructions (not yet published). The main objective is to calculate the upper leaching quantities of toxic metals (As, Cu, Cr, Cd, Ni, Pb and Zn) and polychlorobiphenyls (PCBs) in crushed concrete based on upper tolerance limit for the recipient (s) based on human and eco toxicity.

The third and maybe most important project to influence this report is Waste As Resource (WAR I and II). WAR 2011 has prepared a strategy for a comprehensive solution to be designed and provided for the cement industry. This includes improvements through all stages of production: from extraction of raw materials to the finished manufactured cement. The Resource Group has been working with different types of waste materials internally and externally during the project period.

WAR 2011 is preparing a report "Future challenges for the cement industry”, summarizing the challenges the cement industry faces. Furthermore, it makes some projections regarding the growth in production and key aspects related to the growth including fuel cost, demand of energy efficiency, carbon emission price, emission reduction (e.g. Hg) and biodiversity (e.g. new quarries). Based on these scenarios the most important future threats to the cement industry are ironed out.

In 2012, WAR II will integrate and interact with expertise in SINTEF Building and Infrastructure with regard to the following scientific directions:

1. Fuel and materials substitution - primarily in the cement industry.
2. Optimizing energy consumption in the production of cement
3. Resource Optimal waste management with focus on household waste and the resulting combustion ashes

Konsensus is another important project focusing on LCA. The aim in this project is to make Norwegian actors use a common platform of how to perform whilst performing LCA (Holthe et al, 2011). The knowledge gained from this project has been utilized performing in the VISES project.

# 2 Materials

## 2.1 The case study: Passive house roof construction based on concrete

The case study is a passive house version of a roof taken from the Building Research and Design guide 525.207 (BRD525.207, 2007). The series is an informational database describing building technical solutions produced and recommended by SINTEF Building and Infrastructure.

The passive house roof construction assessed is shown in figure 1. The materials used in this construction is concrete, vapour barrier, mineral wool insulation and bitumen roofing.

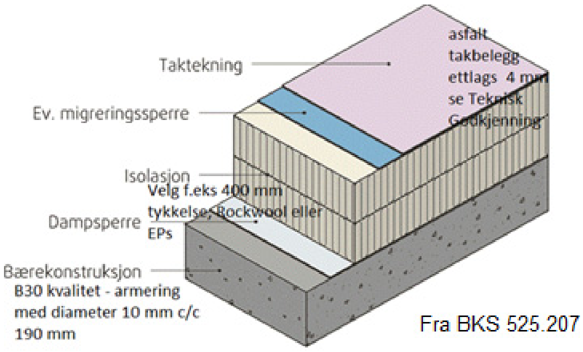


**Figure 1: The chosen roof construction (Byggforskserien 2007).**

The passive house concept was earlier based on a German definition for a low-energy home, with a total energy demand set to less than 100kWh/m$^2$ year. In 2010 a Norwegian standard was developed, adapting these criteria to Norwegian conditions (NS3700 2010). The standard does not provide a short and clear definition of the term, but provides criteria for determining the net energy needs for heating, requirements for heat loss and energy supplies (Rønning et al, 2011). Here it is stated that a passive house roof should not exceed a U-value of more than 0.13 W/m$^2$K. The U-value is a coefficient of thermal transmittance describing how much energy is leaking from the specified element or material. Our case study is a compact roof as the one described in the Building Research and Design guide sheet 471.013 (BRD471.013, 2003). The U-value is 0.09 W/m2K.

Table 1 describes the material characteristics assumed for the analysis. Data describing amounts needed for reinforcement is taken from work done by Tore Jensen. Assumptions taken related to bitumen roof covering are taken from TG nr. 2013, *Icopal Mono ettlags asfalt takbelegg (TG2013, 2011)*. The quality is chosen to be V60. Amounts needed for the vapor barrier are taken from TG nr. 2554, *Tommen Gram Dampsperre (TG2013, 2008)*.

The functional unit of 1m2 is the most used functional unit (in Norwegian based analysis) according to Konsensus I (Holthe et al, 2011).

**Table 1: Material characteristics assumed**

| **Material characteristics** | | |
|---|---|---|
| Concrete | 2400 | kg/m3 |
| Reinforcement steel | 7800 | kg/m3 |
| Vapour barrier (Polyethylene) | 0,139 | kg/m2 |
| Bitumen roofing | 5 | kg/m2 |
| Insulation (mineral wool) | 20 | kg/m3 |

**Table 2: Material input of each selected material to the functional unit (FU).**

| Material input | kg/FU |
|---|---|
| Concrete | 451,2 |
| Reinforcement steel | 14,3 |
| Vapour barrier (Polyethylene) | 0,14 |
| Bitumen roofing | 5 |
| Insulation (mineral wool) | 6,7 |

## 2.2 Chosen scenarios

Three scenarios of material input is compared. The only variable in the three scenarios is the cement. The additives in the concrete, insulation and roofing materials are the same for all scenarios.

The three cement types used, describing each scenario are:

1) Cement from Ecoinvent database: Portland cement (mean European production)
2) EDP-data for standard cement made in Norway (Company: Norcem)
3) EDP-data for low carbon cement made in Norway (Company: Norcem)

All cement types are ment to be used in a light construction. The other material inputs in the scenarios are are mean European production data taken from the database EcoInvent.

## 2.3 Description of the cement scenarios

Cement is the material used to bind the aggregate materials of concrete. Concrete is therefore a combination of a cement and aggregate.

Portland cement (often referred to as OPC, from Ordinary Portland Cement) is the most common type of cement in general use around the world because it is a basic ingredient of concrete. It is a fine powder made from grinding Portland cement clinker.

Clinkers are nodules (diameters, 0.2-1.0 inch [5–25 mm]) of a sintered material that is produced when a raw mixture of predetermined composition is heated to high temperature. The major raw material for the clinker-making is usually limestone (CaCO3) mixed with clay as source of alumino-silicate. The mixture is fed into a kiln and heated to a sintering temperature of 1450 °C, meaning the powdered material is heated to a temperature below the melting point. The atoms in the powder particles diffuse across the boundaries of the particles, fusing the particles together and creating one solid piece. Sintering, with subsequent reworking, can produce a great range of material properties. Changes in density, alloying, or heat treatments can alter the physical characteristics of various products (WikipediaSinter, 2011, Sintering processes).

Control of temperature is very important to the sintering process, since grain-boundary diffusion and volume diffusion rely heavily upon temperature, the size and distribution of particles of the material, the materials composition, and often the sintering environment to be controlled.

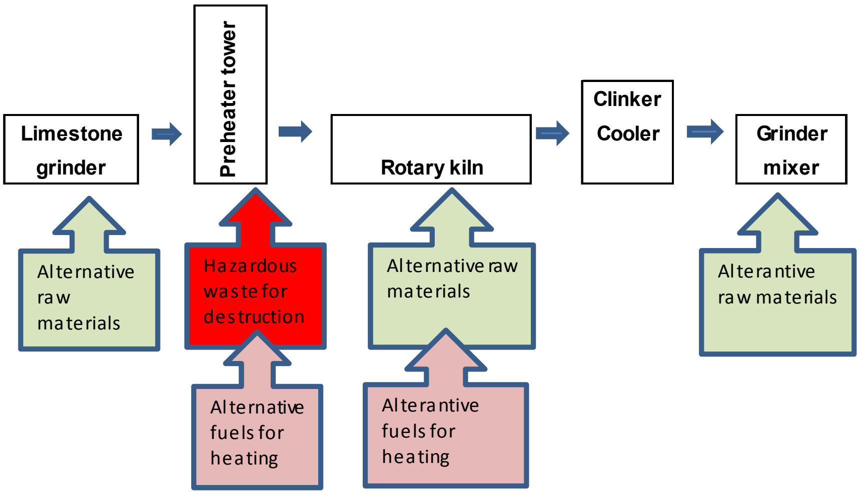


**Figure 2: Schematic description of the cement production process.**

After cooling, a quantity (2-8%, but typically 5%) of calcium sulphate (usually gypsum or anhydrite) is added to the clinker and the mixture is finely ground in the cement mill to form the finished cement powder. The grinding process is controlled to obtain a powder with a broad particle size range, in which typically 15% by mass consists of particles below 5 µm diameter, and 5% of particles above 45 µm. The measure of fineness usually used is the "specific surface area", which is the total particle surface area of a unit mass of cement. The rate of initial reaction (up to 24 hours) of the cement on addition of water is directly proportional to the specific surface area. Typical values are 320–380 m2·kg−1 for general purpose cements, and 450–650 m2·kg−1 for "rapid hardening" cements (WikipediaCement, 2011).

Producing 1 ton clinker involves emission of 400-450 kg $CO_2$. The current aim of the cement industry is to reduce the $CO_2$-emissions from the production plants. There are several possibilities for reformation of the system. Figure 2 describes the different stages of possible use of alternative raw material input lowering the total $CO_2$ emissions.

Heating the limestone liberates $CO_2$, hence one option is to reduce the portion of limestone in the clinker, i.e. replacing it with alternative raw materials. There are also several projects associated with reducing the portion of clinker in the cement, i.e. replacing it with fly ash.

The fuel used to obtain the 1450°C in the kiln is usually fossil fuels like oil and coal. The combustion process liberates $CO_2$. By substituting the fossil fuels with i.e. municipal waste, used tyres, animal bone meal etc. the carbon emission will be reduced. This method is called co-processing (Karstensen, 2011). Coincidently, the incineration of waste will eliminate possibly hazardous compounds even more efficient than a dedicated incinerator since the temperature is very carefully controlled.

Table 3 shows the amounts of clinker, fly ash and energy in standard and low carbon production of cement at Norcem. Because the case study is a light construction (a roof), we can assume the same amount of 300 kg cement per $m^3$ produced concrete is used in all scenarios (Engelsen, 2011), despite the fact that the quality slightly  lower for the low carbon cement with less clinker as raw material.

**Table 3: Presentation of the amount of clinker, flyash and energy in standard and low carbon production of cement at Norcem (LavkarbonEPD 2011; StdEPD 2011).**

| **Pr. ton prod. cement** | **Low carbon cement [kg]** | **Standard cement [kg]** |
|---|---|---|
| Flyash | 300 | 0 |
| Clinker | 600 | 909 |
| Coal | 1193 | 1788 |

Another aim of the cement industry is to lower the energy consumption in the production process. An alternative fabrication technique EMC (Energetically Modified Cement) uses mixtures of cement with sand or with slag or other pozzolan type minerals which are extremely finely ground together. Concrete made from this type of cements can have the same physical characteristics as normal concrete but with 50% less cement in it due to their increased surface area for the chemical reaction. Less cement entails a lower carbon emission and reduced energy consumption. Even with intensive grinding they can use up to 50%  less energy to fabricate than ordinary Portland cements (WikipediaCement, 2011)

# 3 Method and Choices

LCA considers the potential environmental impacts throughout a product’s life cycle from raw material acquisition through production, use and disposal. It is an approved method and is described in the international standard EN ISO 14040. Examples of categories of environmental impacts included in the method can be climate change potential, acidification, toxicity and similar.

## 3.1 LCA theory

LCA method consists of 4 main phases (see figure 3):

1. Goal definition
2. Scope definition
3. Inventory analysis
4. Impact assessment

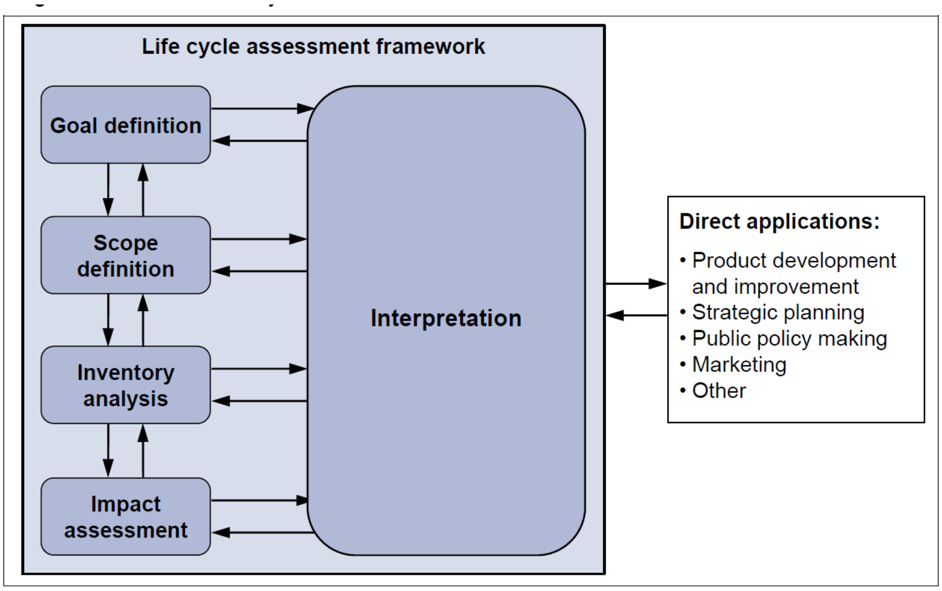


**Figure 3: The LCA framework. Kilde: ILCD Handbook, 2010.**

LCA is a structured, comprehensive and internationally standardised method. It quantifies all relevant emissions and resources consumed and the related environmental and health impacts and resource depletion issues are associated with any goods or services (ILCDhandbook, 2010, p. iv, summary).

**Goal definition**

The EN ISO 14040 standard states that the goal of an LCA includes

- The intended application
- The reason for carrying out the study
- The intended audience, i.e. to whom the results of the study are intended to be communicated
- Whether the results are intended to be used in comparative assertions intended to be disclosed to the public.

The goal definition identifies the purpose with the LCA and the target audience (ILCD Handbook, p. 29). The intended applications of the LCA results are weak point analysis and greening the supply chain. This study will have limited impact coverage, meaning we will only assess greenhouse gas emissions and energy consumption. The reason for carrying out the study is to see whether low carbon cement really is a greener choice than ordinary cement.

**Scope**

The EN ISO 14040 standard (ISO14040:2006) states that the scope of an LCA includes the

- product system to be studied
- functions of the product systems
- functional unit
- system boundary

The scope of the LCA is clinker used in cement production. To compare the different production methods, we use EPDs on low carbon cement and EcoInvent database for the ordinary Portland clinker.

**Functional Unit**

An LCA is always anchored in a precise, quantitative description of the functions provided by the analysed system. The functional provides a reference to which the inputs and outputs can be related (ILCA Handbook, p. 60). The functional unit allows making comparisons that are valid, as the compared objects are comparable. For example, the functional unit for this study may be 1 kg produced clinker, or 1m$^2$ concrete slab.

**System boundaries**

The system boundaries determine which parts of the life cycle and which processes belong to the analysed system and are required for providing its function as defined by its functional unit. A precise definition of the system boundaries is important to ensure that all attributable or consequential processes are actually included in the modelled system and that all relevant potential impacts on the environment are appropriately covered (ICLD Handbook, p. 94-95).

It seems there is a predominance of LCA studies operating with a cradle-to-gate scenario, starting with the extraction of raw materials but ending at the gate of the construction site not including the construction process, service life or waste scenario.

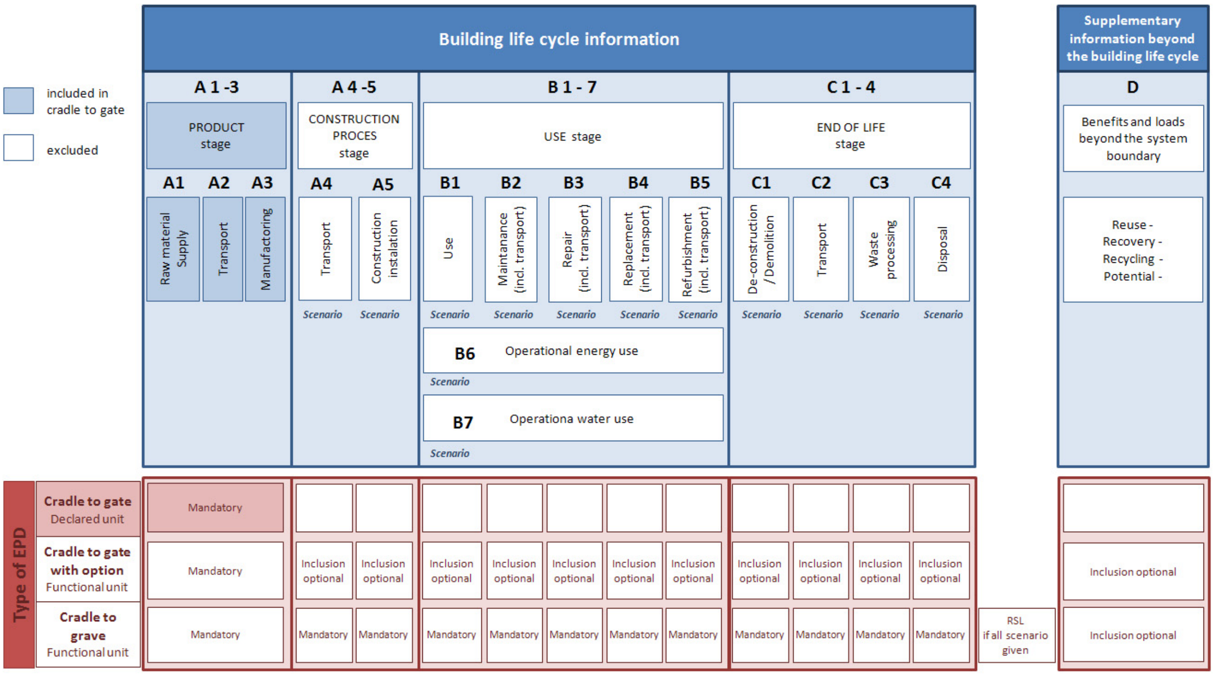
## 3.2 Functional unit and system boundaries in current study

In the forthcoming European standard, CEN prEN 15804 the building life cycle is divided into four main stages, each consisting of several modules which can be seen in figure 4 (prEN15804 2010):

- Product stage (modules A1 raw material supply, A2 transport, A3 manufacturing)
- Construction process stage (modules A4 transport, A5 construction installation process)
- Use stage ( B1 use, B2 maintenance, B3 repair, B4 replacement, B5 refurbishment)
- End of life stage ( C1 de-construction/demolition, C2 transport, C3 waste processing, C4 disposal)

This study is a cradle to gate study (modules A1-3) with options, including the module A4 transport to construction site.

**Table 4: Presentation of modules when performing a LCA (prEN15804 2010)**



🟦 included in cradle to gate

☐ excluded

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Building life cycle information | | | | | | | | | | | | | | | Supplementary information beyond the building life cycle |
| | A 1-3 | | | A 4-5 | | B 1-7 | | | | | C 1-4 | | | | | D |
| | PRODUCT stage | | | CONSTRUCTION PROCES stage | | USE stage | | | | | END OF LIFE stage | | | | | Benefits and loads beyond the system boundary |
| | A1 | A2 | A3 | A4 | A5 | B1 | B2 | B3 | B4 | B5 | C1 | C2 | C3 | C4 | | |
| | Raw material Supply | Transport | Manufactoring | Transport | Construction instalation | Use | Maintanance (incl. transport) | Repair (incl. transport) | Replacement (incl. transport) | Refurbishment (incl. transport) | De-construction /Demolition | Transport | Waste processing | Disposal | | Reuse - Recovery - Recycling - Potential - |
| | | | | *Scenario* | *Scenario* | *Scenario* | *Scenario* | *Scenario* | *Scenario* | *Scenario* | *Scenario* | *Scenario* | *Scenario* | *Scenario* | | |
| | | | | | | B6 Operational energy use<br>*Scenario* | | | | | | | | | | |
| | | | | | | B7 Operationa water use<br>*Scenario* | | | | | | | | | | |
| Type of EPD: **Cradle to gate** Declared unit | Mandatory | | | | | | | | | | | | | | | |
| Type of EPD: **Cradle to gate with option** Functional unit | Mandatory | | | Inclusion optional | Inclusion optional | Inclusion optional | Inclusion optional | Inclusion optional | Inclusion optional | Inclusion optional | Inclusion optional | Inclusion optional | Inclusion optional | Inclusion optional | | Inclusion optional |
| Type of EPD: **Cradle to grave** Functional unit | Mandatory | | | Mandatory | Mandatory | Mandatory | Mandatory | Mandatory | Mandatory | Mandatory | Mandatory | Mandatory | Mandatory | Mandatory | RSL if all scenario given | Inclusion optional |

The functional unit is set to 1 $m^2$ passive house roof construction (residential building), with a U-value of 0,09 $W/m^2K$.

The simulations are done using the software SimaPro and the method ReCiPe (H), midpoint view.

The construction site is assumed to be located in Oslo city center. Every material is transported with the same kind of vehicle from plant to construction site. We assume the same transport distance (production and construction site in Norway) for each of the materials in all scenarios. The transport is carried out by lorry. We assume a vehicle of 20-28 ton for all material inputs. Transport is measured in ton*km.

**Table 5: Transport data for each material from production site to construction site.**

| **Material** | **Producer** | **Distance [km]** | **[tkm]** | **Vehicle [t]** | **Link** |
|---|---|---|---|---|---|
| Concrete | Norcem, Slemmestad | 31 | 13,99 | 20-28 | www.heidelbergcement.com/no |
| Steel (reinforcement) | Sluppen, Trondheim | 492 | 7,01 | 20-28 | www.smith.no |
| Mineral wool | Glava, Askim | 54 | 0,36 | 20-28 | www.glava.no |
| Roofing/vapour barrier | Isola, Porsgrunn | 141 | 0,72 | 20-28 | www.icopal.no |
| | | | | | |
| Total | | 718 | 22,09 | | |

- The cement is produced in Brevik, and the concrete is mixed in Slemmestad in Asker.
- The steel for the reinforced concrete is produced in Sluppen in Trondheim.
- The mineral wool is produced in Askim.
- The roofing and the vapor barrier are produced in Porsgrunn.

The main impact categories chosen are Climate Change potential (unit: kg $CO_2$ eq) and accumulated energy (unit: MJ).

# 4 Simplifications and data quality in the analysis

## 4.1 General data quality

When considering data from both mean European data from Ecoinvent and Norwegian EPDs there are some uncertainties which must be mentioned. The main problem considering the scenarios is the fact that we do not know the exact inputs related to the production of cement presented in the Environmental Declarations (EPD) of the production in Norcem.

## 4.2 Production stage

Unfortunately, the Ecoinvent database contains no data for extruded polyethylene. The only registered value is for granulate polyethylene. This excludes the energy consumption for extruding (melting and pressing) the polyethylene at plant. Since this contribution is considered very small compared to the process of producing the granulate itself, and the amount is accordingly minute, it was decided to incorporate the granulate data.

In addition the values from processing of bitumen sheeting is not considered and included in the analysis.

There is a gap between the delivery to the building site and the completion of the construction. Inputs related to the construction of the roof such as electricity used to illuminate the building site and the food produced for the construction workers,  have been eliminated from the analysis.

## 4.3 Service life

Not yet included.

Known maintenance: The life time of bitumen sheeting is about 25-30 years and must therefore be changed twice during the lifetime of 60 years. The insulation layer is durable thorough the entire service life if the building is constructed properly (Gåsbak, 2011).

## 4.4 End of life

The analysis do not include demolition describing the end of life-phase .This phase includes the potential of absorbing some of the $CO_2$-emissions from the cement production thorough the accelerated carbonization after demolition. Furthermore it involves the possible reuse of concrete, i.e. as filler under parking lots. There are also unsolved problems regarding the special landfill for the bitumen and plastic materials. They can potentially enter into the cement production via co-processing, but it is doubtful that this is done in real life. We will, however, include co-processing in COIN 2012.

# 5 Results

Figure 4 shows the $CO_2$ emissions related to the three scenarios.

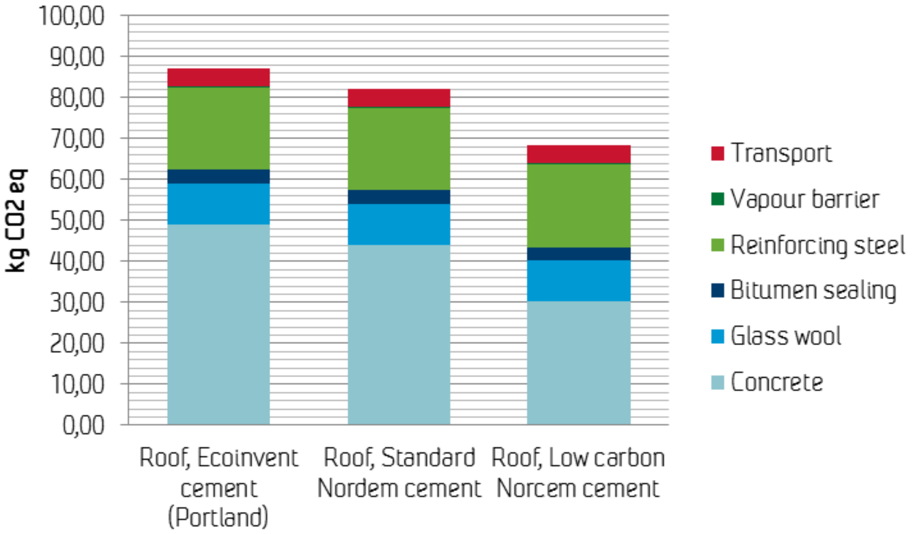


**Figure 4: $CO_2$ emissions from the roof construction using 3 different cement types**

The results show that the material contributing the most to the total emission output is the concrete. If the reinforcement is included as well, it is clear that the use of this heavy material has a very large contribution to the total output in every scenario.

The $CO_2$ emissions are highest for the EcoInvent-cement. The results show that the Norwegian standard concrete is 10% "better" than the EcoInvent concrete. The low carbon concrete is 38% "better" than the EcoInvent concrete. This is probably due to several factors, first and foremost to the production methods of the cement. The "Portland cement" has a kiln fueled with "traditional" fossil fuels. The low carbon cement consists of 30% fly ash from combustion of coal in the kiln which lowers the emissions to a great extent.

Figure 5 shows the accumulated energy related to the three scenarios. As can been seen in the graph, the current Norwegian way of producing the concrete is actually 18% higher than the EcoInvent concrete.

The low carbon cement demands the least energy use and is 11% "better" than the EcoInvent concrete.

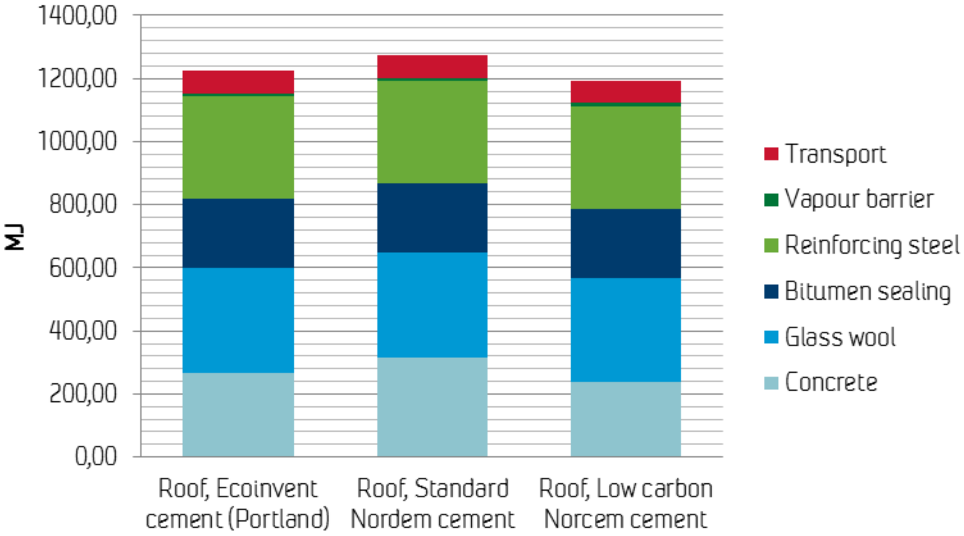


**Figure 5: Embodied energy in the roof construction using 3 different cement types**

# 6 Discussion

The aim of this study is to:

1) Learn about the different aspects of using the LCA methodology:
    a. The challenges of limiting the analysis in the goal and scope
    b. The challenges of the inventory analysis and data quality
    c. The challenges of choosing impact categories
2) Increase knowledge using the LCA-tool SimaPro
3) Use the LCA methodology to assess the environmental load of a passive house roof construction
4) Identify the concrete with the lowest GHG emissions and embodied energy

It is our understanding that this aim has been fulfilled. Learning and understanding has grown through reading, practicing and discussions during the 2011 fall semester. A special interest in concrete made us choose three scenarios in order to identify the “best case” concrete and to analyse what impacts concrete have on the total environmental load for the three scenarios. On the basis of the results it is clear that the low carbon cement has lower carbon emissions and energy consumption than the other alternatives studied, but there are some uncertainties on related to the obtained results.

## 6.1 Uncertainties

Experiences from other studies show that the emission factor related to the electricity mix influences the result to a great extent. Since we do not know the electricity mix used in the EPDs, it makes us less able to make conclusions on why one cement has lower emission outputs than the other.

LCA as a tool for analyzing can be used in many ways, resulting in different outcomes. To be able to read conclusions on the basis of results it is very important with transparency, making the reader aware of choices and inputs made which all together influence the results. Because there is still a lack of knowledge of inputs in the EPDs, it is difficult to draw clear conclusions.

## 6.2 Cement production in a LCA perspective

A few years ago, there were restrictions regarding use and storage of fly ash. At present, there are no clear rules on how to assess this replacement of limestone (or clinker) in an LCA-perspective. The clinker content in the cement controls the $CO_2$-emissions from the concrete. The low carbon cement consists of 30% fly ash, which makes it possible to remove parts of the clinker in the cement. Are we allowed to regard it a contribution on the "plus side" because a waste problem is removed? Should we consider it a neutral factor, since the fly ash will return as a waste problem in the future? Are we simply postponing a problem, and how harmful is the fly ash? Will it surpass to category of hazardous waste in a few years? Is it part of an entirely different LCA system, not connected to the clinker production?

Often, the amount of cement in concrete is disproportionately high. With more cement, the concrete dries faster and is more durable. A roof should be solid, but there is less need for load carrying capacity. In other words, the cement ratio can be reduced compared to the use in heavier construction, like a bridge. When clinker is replaced with fly ash, the load bearing capacity of the concrete may drop and the amount of added cement must be increased accordingly. Since our case study is a light building element as a residential roof, we can assume the same amounts of cement in the concrete needed for the three scenarios.

The production of 1 ton clinker requires 400 kg fossil fuels. The fuel can be replaced with i.e. car tires or waste, which is specified in the EPD as reuse. The alternative fuels often have more heat value than coal, and any hazardous waste is degraded. There are no data available on how to include co-processing in LCA. Are we allowed to consider it a "double plus" when fossil fuels are replaced, hazardous waste is removed and the environment is saved by a dedicated waste incinerator?

Another factor is that the amount of coal refers to the production of 1 ton cement, not 1 ton clinker. This means that any type of cement with reduced amount of clinker will be less energy intensive.

# 7 Conclusions and further work

On the basis of the results it is clear that the low carbon cement has lower carbon emissions and energy consumption than the other alternatives studied, but there are some uncertainties regarding the results. There are uncertainties regarding comparability of the results in the study, due to unspecified data input used in the EPCs. Improvements in this area are part of our aim in COIN in 2012. There is room for improvement of the input data, and this is part of our aim for 2012.

Further work for COIN 2012:

- Consideration of more impact categories
- Total life cycle: Cradle-to-grave
  - Include maintenance and service life of the building
  - Include end of life treatment. There is very little input data on waste scenarios.
- Analyzing more types of concrete/cement
  - Consider quality differences of the input data
  - Include co-processing in the LCA.
- Sensitivity analysis
  - Cement from EPD vs. cement from EcoInvent; Are they really comparable and what contributes to the different results?

Our goal for COIN 2012 is to complete the LCA and include service life and waste scenarios. In this matter, the results from the KLIF project will be helpful.

If possible, we would like to include the results from COIN and WAR and perform a LCA on "best practice cement", utilizing state of the art production methods. The data for these products are not available at present, but we hope for access and participation from the participating partners.

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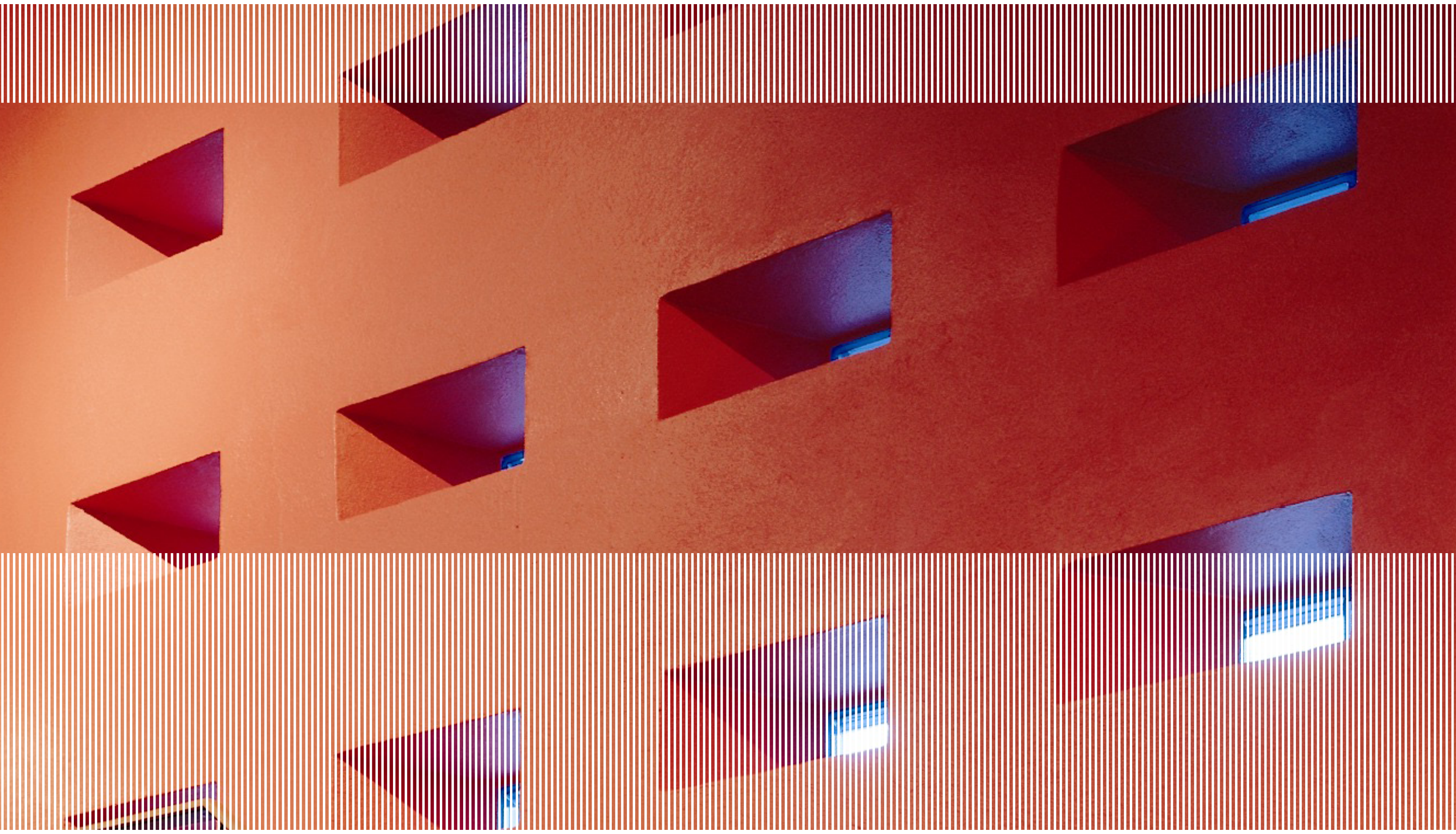

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