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Carbon Footprint of Ready Mix Concrete and the Role of Environmental Classification Systems

Master of Science Thesis in the Master Programme Industrial Ecology

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Abstract

This Master Thesis is performed as a case study of The Carbon Footprint of Ready Mixed Concrete (RMC) produced at Thomas Concrete Group AB and the Role of Environmental Classification Systems and it has three main parts. The first part is related to the role of Environmental Classification Systems,such as LEED and BREEAM, in reducing the carbon footprint of RMC and in achieving higher rating of concrete buildings. Important stakeholders of the commissioner company were interviewed. About 80% of the interviewees said that these systems have a future and can play an important role in reducing the CF of the construction sector. The LEED system does not incorporate the CF category directly while BREEAM does and uses the LCA approach for the CF calculations of the buildings. According to the LEED material Credit-4 Ready Mixed Concrete should have a minimum of 10 to 20% post industrial materials (e.g. slag, fly ash etc.) and 100% according to the BREEAM by weight of cement. These conditions have been applied and the results of this study indicates that by using 20-40% slag in ready mixed concrete, 17-38 kg CO2-eq/m^{3}of concrete can be avoided, and this corresponds to a reduction of about8-12%.

The LCA(cradle-to-gate) approach was used and PAS 2050:2008 CF methodology was followed for the CF calculations of the Ready Mixed Concrete. The CF of five main types of RMC has been calculated. The results indicate that 70-90% of the carbon footprint stems from the production of Portland cement while 3-7% comes from transport operations.

At the end a CF tool in excel 2007 was developed for the Thomas Concrete Group AB. The input required, for this tool,is the concrete recipe and transport distances. As soon as inputs are completed the results are generated automatically. The results on CF and NOx are presented by individual source and in total both in quantitative and graphical formats.

Confidential information has been omitted in this report.

Key words: *Environmental Classification Systems (ECS), Leadership in Energy and Environment (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), Ready Mixed Concrete (RMC), Life Cycle Assessment (LCA), Carbon Footprint (CF),Publically Available Specification 2050(PAS2050), Thomas Concrete Group AB (TCG), Portland cement*

Abbreviations

B2B	Business to Business
B2C	Business to Consumer
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
CF	Carbon Footprint
EPD	Environmental Product Declaration
GWP	Global Warming Potential
EU	European Union
ECS	Environmental Classification Systems
EUGB	European Union Green Building
GHG	Greenhouse Gas emissions
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LEED	Leadership in Energy and Environmental Design
PAS	Publically Available Specification 2050
PLC A&R	Product Life Cycle Accounting and Reporting
RMC	Ready Mixed Concrete
EMS	Environmental Management System
TCG	Thomas Concrete Group AB
FB	Färdig Betong

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1 Introduction

Concrete has played a great rolesince 7000 BC in the development of the building infrastructure for human settlements (British Cement Association, 1999).Concrete is ubiquitous in our built environment and as such has played a major role in the shaping of civilisation as it provides a cost-effective, durable and strong materialto homes, schools, hospitals, dams and so on. The rapid growth of world population and the growing concern of urbanization are factors stressing the importance of environmental and ecological consequences. The last few decades have spurred much debate on global warming and other ecological changes (Kejin Wang, 2004; RMCAO, 2011) due to increased CO_2 concentration.

The largest producers of carbon dioxideinclude the chemical, petrochemicals, iron and steel, cement, paper and pulp and transport industry.However, the Portland cement industry is one of the largest producers of carbon dioxide and is responsible for approximately 7% of the world's carbon dioxide emissions (*RMCAO, 2011*; Sakai, et al. 2008). Worldwide, the concrete production is about 12 billion tons per yearand approximately 1.6 billion tons of Portland cement, 10 billion tons of sand and rock, 1 billion tons of water are used annually. On average, one ton Portland cement clinker requires 7000MJ energy and 0.7-1.0 ton CO_2 is emitted depending to the kiln type (WBCSD, June 2009). However, The National Ready Mixed Concrete Association (NRMCA) has vision of reducing 20% to 30% each of embodied energy, potable water and carbon footprint (CF) of ready mixed concrete by 2020 and 2030 respectively (NRMCA, 2009).

Sustainable development, global warming,energy conservation are growing issues that owners, designers, material suppliers and contractors must address in order to identify and offer products and services as green solutions. Public thinking is also changing as they recognize the significance of addressing these important issues. The concrete and construction industries have realised that addressing these issues is neededto show their sustainable development responsibility and to become a market competitive (*RMCAO, 2011*).

The climate change has gained a significant attention since last few years and is now a priority of academia, political and corporate agendas (Azar, 2008). A scientific method was developed by Keeling near 1938 to calculate the CO_2 concentration in the atmosphere. He came up with the result that the annual increase of CO_2 at that time was about 0.6 ppmv according to his method (Bohlin, 2008). Debate on this method and the consequences of the increase of CO_2 on the earth climate hascontinuedsince that. In response of that debate the Intergovernmental Panel on Climate Change (IPCC) was founded in 1988 by the World Metrological Organization (WMO) and the United Nations Environment Programme (UNEP). The function of this benchmark was to assess *"[...] the scientific, technical and socioeconomic information relevant for understanding the risk of human induced climate change"* (IPPC, 2007b; Ch. 1, p. 26).The IPPC (2007a; p. 17) came up with the conclusion, based on some scientific facts, that "*most of the observed increase in global average temperature since mid-20th century is very likely to be an increase in anthropogenic GHG in the atmosphere".*GHG emissions havebeen increased by an average of 1.6% per year and the atmospheric CO_2 concentration has increased by almost 100 ppm in comparison to its preindustrial level. The CO_2 level in 2005 was 379 parts per million (ppm) and the current estimated total GHGs concentration is 455ppm CO_2-eq which is deemed to have impacts on climate system (IPCC, 2007; 4th assessment report, p. 97). To mitigate the climate change the Kyoto protocol 2005 was launched to bind countries legally and develop international consensus on GHG emissions reduction by the UNFCC (UNFCCC, 2009).

After Kyoto protocol many environmental policies (emission permits, carbon tax etc.) have been introduced by different countries incorporation with local and international Non-governmental organizations (NGOs) and Environmental Protection Agency's (EPA). The large number of environmental and non-environmental NGOs in collaboration with media has done great work in developing environmental awareness in general public. This information has created a big market for environmental information of products and services. In response of this demand many environmental tools have beenintroduced to evaluate the environmental performance of products and to present them to the market. One of them is carbon footprint of products that just covers the one aspect (climate change or global warming potential) of the products. Much debate is still going on over different issues related to the methodology and others (Weidema et al. 2008; Wiedmann & Minx, 2007).

Concrete,after water,is the most widely used material in the world. Cement and concrete production have had lot of benefits for humankind such as to provide strong, durable and long lasting buildings and roads, bridges and railways for transportation and so on (Kawai, et al. 2005). However, it also affects local and global environment such as global warming due to GHG emissions, depletion of natural and energy resources, airpollution and waste etc. In order to be a part of collective contribution towards the sustainable challenges, many types of counter measures such as use of fly ash, slag and otherrecycled materialsin concrete mixes [e.g. the concrete centre. UK: 2007] have been tested since long time. This idea of using recycled materials in cement and concrete productionis likely a fast way for the respective industriesto minimize its environmental impacts (Kawai, et al. 2005). Hence, the NRMCA has vision to increase the use of recycled materials in concrete industry 200% by 2020 and 400% by 2030 (NRMCA, 2009).

As the building sector affects the environment through the consumption of resources at many stages there was a need to set standards for the measurement of environmental impactsby this sector for individual materials, composite products and as a whole system. Hence, in 1990 the Building Research Establishment (BRE) established the BREEAM and United States Green Building Council (USGBC) were founded. The purpose of these was to promote sustainability in building designs (Wikipedia, 16 Feb. 2011). These were the two foremost organizations which came up with BRE Environmental Assessment Method (BREEAM) and Leadership in Energy and Environmental Design (LEED) Environmental Classification Systems respectively. Since that time a process of continuous improvements has been followed and in the last few years these systems have introduced green certification or rating schemes for buildings. More detailed information is available in chapter 3.

In recent years the use of different tools has become a norm to evaluate environmental impacts of products and services. The most common tool is the carbon footprint. Many companies have created such tools for the convenientness of their clients and internal use.The CEMEX company is one of the cement, aggregate and ready-mix concrete producers that recently unveiled its carbon footprint tool (CEMEX, 2010).

Thomas Concrete Group (TCG) has strong believe that long term profitable and competitive business can never be achieved without consideration of environmental concerns in their activities. Based on this, TCG wants to use LCA approach to communicate its environmental contribution to its stakeholders (TCG, 2011) and to be able to compare the impact of different raw materials (such as mineral additives, admixtures, natural sands, and crushed aggregates).

The report on sustainability performance has become a part of companies' annual report.This concept is growing also in the construction industry. In order to meet future demands the TCG wants to develop a computer-based carbon footprint tool that makes it easy for their production planners to calculate the GHG emissions associated with their production of ready-mix concrete.

This study is conducted for Thomas Concrete Group in collaboration with Chalmers University of Technology. In this master thesis GHG emissions associated with ready mix concrete production are recorded based on the cradle to gate life cycle methodology. The role of environmental classification systems in the development of environmental performance of buildings and other concrete infrastructure is also studied.

1.1 Aim & scope

The scope of this master thesis covers three interconnected areas. One is the calculation of CF of ready mix concrete produced by the TCG ready mix plants,and more specifically concrete produced at Färdig Betong AB Ringögatan 14 GöteborgSweden (a TCG ready mix concrete plant). The implementing of life cycle analysis (cradle-to-gate) tool according to an appropriate CF methodology (e.g. GHG protocol, PAS 2050 and EPD etc.) is suggested to be adoptedfor calculating GHG emissions from RMC production.

The second goal is to develop a CF tool in Microsoft office Excel 2007 that can be used later on to calculate the carbon footprint of different ready mixedconcrete compositions (RMC) produced at any one of the TCG ready mix concrete production plants. The tool later on will be used by the Thomas Concrete Group AB to inform its customers about the environmental impact of their choice of product. At this stage only the environmental impact,climate change or GWP is in focus.

The third main intention is to analyze the major environmental classification systems (ECS) but more specifically LEED and BREEAM (BRE Environmental Assessment Method) with particular focus on environmental information related to concrete. In addition, identification of environmental information exercised by different relevant stakeholders e.g. property developers, contractors, architects, and engineering consultants through these systems and estimation of their satisfaction level of use of these ECS was to be analysed. At the end, conclude, what the ECS say about the CF of materials, concrete in particular, used for construction by analysing the LEED and BREEAM manuals and based on the information gathered from the concrete stakeholders. Finally, implementation of possible requirements posed by the selected ECS on concrete production technique to look at CF difference as compared to the normal way of concrete productionhas been done.

1.2 Method

The processing method of this master's thesis is illustrated in figure 1. Before starting, the thesis, requirements and some choices about the carbon footprint tool and data boundaries were already made by the commissioner company (TCG). These include, focus only the environmental impact "climate change or CF" and following cradle-to-gate life cycle methodology instead of full LCA (cradle to grave). For the CF tool MS office Excel 2007 was decided to be used.

At the start of this study, a literature reviewand production plant visit, including the concrete testing laboratory, were performed. The scope of ECS and the identification of stakeholders were decided through discussion with advisors and supervisor. The interviews were done through personal meetings with the selected stakeholders.

The site specific data about the resources production was collected with the help of advisor and company purchase department.

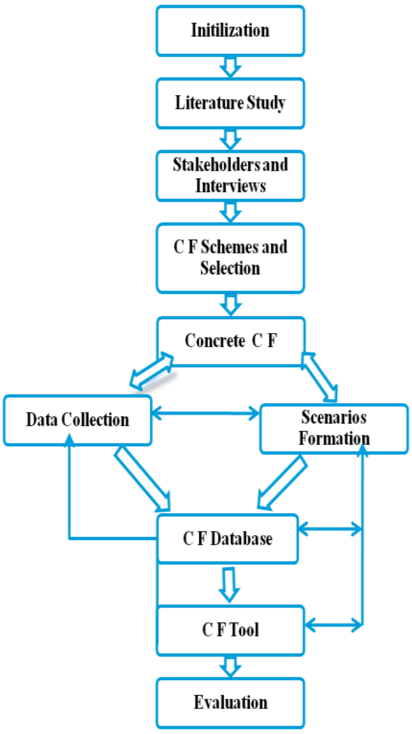


Figure 1: A systematic diagram showing the working process adopted to develop a Carbon footprint Tool for Concrete Mixes at TCG AB

The data on processes under direct control of the company was collected and compiled through several meetings with environmental manager (*AnnikeAndreasson*) of TCG, production manager (BjörnAndersson) and advisor (IngemarLöfgren).

1.3 Limitations

At starting phase earlier work on carbon footprint of ready mix concrete was reviewed to explore important processes and material flows. From this work it was concluded that the production of cement and the transport of resources are more important ones and will be analysed more carefully.

After the detailed visit of plant, concrete testing laboratory and availability of data it was decided to exclude the testing and water production processes. Due to time limitations and negligible emissions of other GHGs, except CO_2, CH_4 and N_2O, were decided to be left out.

The emissions from business travels were decided to be excluded due to time constraint and dispersion of data.

2 Ready Mix Concrete Production and Resource Materials

2.1 The Thomas Concrete Group and Färdig Betong

Thomas Concrete Group AB (TCG), through its subsidiaries, is a family owned multi-national ready-mix concrete producer with its headquartered in Gothenburg, Sweden. The Group operates in Sweden, Germany, Poland, and United States. TCG produce about 4 million cubic meters concrete annually; have 1300 employees, and a turnover of about 400 MEUR. Färdig Betong, is a part of TCG which operates in Sweden, deliver ready-mix concrete to construction sites for bridges, roads, houses, buildings etc. Butit also produces permanent precast formwork systems for slabs and walls (TCG, 2011).

2.2 Ready Mixed Concrete production, a brief sketch

The annual concrete consumption is about 5.57 billion m^3 (Mindess, et al. 2002). For Sweden, the total ready mixed concrete production during 2009 was 2.8 million m^3 (ERMCO, 2009)and in USA it was about 300 million m^3 in 2000 (Mindess, et al. 2002).

The main ingredients of concrete are the Portland cement (250-400kg/m^3), fine aggregates (700-900 kg/m^3), coarse aggregates (1000-1330 kg/m^3), water (100-200 l/m^3) and chemical admixtures less than 1% or (5-10kg/m^3). However, the ingredients and composition varies depending on compressive strength and other special characteristics required (Alhozaimy, et al. 2011). The process of production is described in more detail in section 6.2. The over all quality of concrete is examined by its compressive strength, water/cement ratio (w/c), and workability (e.g. slump). The concrete compressive strength in the European Standard (EN 206-1)[1]is based on the compressive strength being determined on cylindrical specimens but as an alternative cubical specimen can be used. The notation for the compressive strength class is Cxx/yy, and where xx and yy stand for cylinder and cube compressive strengths respectively. E.g. C30/37 corresponds to a concrete with a characteristic compressive strength of 30 MPa determined by testing cylinders and 37 MPa determined by testing cubes.

2.3 Concrete resource materials

2.3.1 Cement

There exists a wide variety of cements depending on the constituents' composition. The most common and widely used is Portland cement whose main constituents are limestone and clay or shale. But depending on the mineral composition of the limestone and the clay other materials may have to be added to get the correct mineral composition.

[1] EN 206-1 stands for European standards for concrete specifications, performance, production and conformity.The standard specifies requirements for:
- concrete composition and materials
- characteristics of the concrete mass and the hardened concrete, including conformity verification
- specification of concrete
- supply of concrete mass
- production control
- criteria and evaluation of conformity (http://www.sis.se)

The grinded limestone and clay are mixed to a raw meal which is burned in a rotary kiln at 1400-1600°C. The resulting material is called Portland clinker which after grinding and mixing with gypsum ($CaSO_4.2H_2O$) is referred to as Portland cement. The gypsum is added to control the early reaction of tricalciumaluminate (C_3A) and to avoid flash setting of concrete. The production of cement clinker is a high energy consumption process and in this process calcination of limestone ($CaCO_3$) to calcium oxide (CaO) occurs and this releases CO_2 (about 440 kg CO_2 per ton $CaCO_3$). The calcium oxide (CaO) reacts in the kiln (at certain temperatures) with other minerals exiting in the clay to form the main Portland clinker minerals, namelyalite (C_3S), belite (C_2S), tricalcium aluminate (C_3A) and ferrite (C_4AF) (Mindess, 2002; Chp.3, p.20-21).

The cement types used in Europe (defined in SS-EN 197-1) are listed in Table 1. The main constituents in the cements used are, apart from Portland cement clinker (K), Granulated slag (S), Silica dust (D), Natural and industrial pozzolans (P or Q), High silica and limestone fly ashes (V or W), Burnt shales (e.g. oil shale) (T), and Limestone (L or LL).According to the European Standards EN-197-1: 2000[2] cement is classified into 5types CEM I, CEM II, CEM III, CEM IV and CEM V (SIS, 2011).

Table 1: Cement Types and Portland Clinker percentage

Cement Type		Portland Clinker Composition
CEM I	Portland cement	95-100%
CEM II	Portland-composite cements (mainly consisting of Portland cement clinker)	65-94 %
CEM III	Blast furnace cement	5-64%
CEM IV	Pozzolanic cement	45-89%
CEM V	Composite cement	20-64%

2.3.2 Aggregates

In concrete production aggregates are classified as fine and coarse aggregates. The standard aggregates (sizes 0-4, 4-8, and 8-16, 16-22 mm) are common and covers 90% of aggregates used in concrete production.

According to the EN 12620:2000 European standard for aggregates, aggregates are classified as given in table 2. Further these are graded into coarse (passes through sieve size 11.2mm), fine (passes through 4mm sieve size), natural (99% passes through 8mm sieve) and all-in(passes through ≤ 45 mm sieve) types based on the particle size and grading should comply to European concrete aggregate standard EN 933-1.

Table 2: Aggregates class by density (source: Sika Concrete Handbook 2005)

Aggregate Class	Density
Standard aggregates	2.2 – 3 kg/dm³
Heavyweight aggregates	> 3.0 kg/dm³

[2] EN-197-1: 2000is aEuropean standardon Cement-part 1 - Composition, specifications and Conformity criteria for common cements. can be found at (www.sis.se)

Lightweight aggregates	< 2.0 kg/dm³
Hard aggregates	> 2.0 kg/dm³
Recycled granulates	approx. 2.4 kg/dm³

The texture, water content and impurities in aggregates are important factors. These factors influence water to cement ratio and ultimately concrete quality (Mindess, 2011).

2.4 Supplementary cementitious materials

The cement production is a high energy consumption and GHG emission process. The most effective means of reducing them are to substitute cement by other cementitious materials, referred to as supplementary cementitious materials (SCM).

Each kilogram of Portland cement reduction in concrete means 0.6-1.0 kg of CO_2 and 5.04 MJ of energy saving. Supplementary cementitious materials (SCM) are either pozzolanicor latent hydraulic materials and are oftenby-products of other industrial processes. The most frequently used SCMs are fly ash, furnace slag and silica fumes (Hicks, et al. 2009; Mindess, et al. 2011).

Fly Ash: It is a fine powder of mainly spherical, glassy particles, derived from burning of pulverised coal and extracted from the exhaust gases by means of electrostatic filters. It has pozzolanic properties and consists essentially of silicon dioxide (SiO_2) and aluminium dioxide (Al_2O_3). Its use to substitution level of 10-15% is practiced in concrete industry. At water/cement (w/c) ratio ≤0.30 up to 60% Portland cement can be replaced with fly ash. However, it is not possible for all types of concrete because at high replacement levels the carbonation resistance of the concrete is reduced.(Mindess, et al. 2011; Ch.1, p.6).

Granulated blastfurnaceslag: It is a by-product of pig iron and steel industry with a mineral composition is closed to Portland cement.According to EN 15167-1[3], granulated blastfurnace slag is made by rapid cooling of a slag melt of suitable composition, obtained by smelting iron ore in a blastfurnace, consisting of at least two thirds by mass of glassy slag and possessing hydraulic properties when suitably activated. It can substitute cement from 25-85% and its use is very common in European Union (Mindess et al. 2011; Ch.1, p.6).

Silica Fumeis, according to EN 13263-1[4], very fine particles of amorphous silicon dioxide (SiO_2) collected as a by-product of the smelting process used to produce silicon metal and ferro-silicon. It is 100 times finer than cement and is a highly reactive pozzolanic material. It is used in concrete when compressive strength 90MPa or higher is required (Mindess et al. 2002; Ch.19, p.522).

Fillers: Fillers are used in concrete production to fill the smallest cavities between the aggregates and thus reduce cement content, improve durability and environmental profile of concrete. Lime stone powder is a frequently used filler.

[3]EN 15167: Ground granulated blast furnace slag for use in concrete, mortar and grout – Part 1: Definitions, specifications and conformity criteria.
[4] EN 13263-1: Silica fume for concrete – Part 1: Definition, specification and conformity criteria.

Admixtures: The frequently used chemical admixtures at concrete industry are superplasticizers, air entrainers, retarders and accelerators.

Air entrainers: These are used to entrain, stabilize and distribute air bubbles in fresh and harden concrete. It is dosage typically from 0.2 to 0.3% by weight of cement (CAA, 2006a). Entrained air improves the workability of concrete and could be used, similar to a water reducer, to reduce the water content. About 3.5-8% (35 to 80 litres per cubic meter of concrete) of air can be entrained using air entrainers. For concrete exposed to freeze-thaw conditions, air entrainment is used to improve the durability. The air bubbles provide free space for the ice to expand and thus improve freeze thaw properties of concrete(Mindess et al. 2011; Ch.10, p.69-73; Sakai, et al. 2006).Concrete with approximately 4- 6% entrained air is more durable and sustainable than concrete with no entrained air.

Superplasticizers: The most known market superplasticizers are of the following types.

i. Lignosulfonates
ii. Polynaphthalenes
iii. Polymelamines
iv. Polycarboxylate ether

These are also called high range water educing agents because of their ability to reduce water content in concrete. These admixtures are typically used in the range 0.7 to 2.5% by weight of cement (CAA: 2006b). The key factor is the use of right amount and a compatible one (Mindess, et al. 2011; Ch.7, p.124-137; Sakai, et al. 2006).

Accelerators: Calcium nitrate and calcium nitrite are both effective set accelerators. These are mixed to increase the rate of hydration of Tricalcium silicate (C_3S) and Tricalciumaluminate (C_3A) phases of the cement. The use ranges 0.5 to 2.5% by weight of cement, providing earlier heat evolution and strength development of concrete (CAA, 2006c; Sakai, et al. 2006)

3 Environmental Classification System

3.1 Introductions to Environmental Classification Systems

The beginning of the green building movement links to the early nineteen century while this concept gained momentum in last decade. Several techniques have been applied to huge building projects such as the use of deep-set windows for Flatiron Building and the Times Building in New York and the use of retractable shelter design for the Carson Pirie Scott department store in Chicago improved indoor air quality and energy requirements (Brook, 2003 p. 4). These two and other such experiments remained very successful but still until 1970 this greening building movement could not get high recognition as a whole. The oil crisesin 1970 to 1974 gave momentum to this movement in USA and EU.

However, since 1990 a large number of green rating systems have been introduced by different organizations. Only a very few of them are internationally acceptable as LEED and BREEAM and most of them are limited to a specific country such as Miljöbyggnad, Miljöstatus, P-märkning (Sweden), CASBEE (Japan and Asia), DGNB Certification System (Germany), and some are for a specific region like Green Building (GB) (Ispra, 2009).

The selected ECS for detail study in connection to CF of ready mix concrete (RMC) are LEED and BREEAM as described in aim and scope session 1.1 of this report. The further discussion is about how the LEED and BREEAM rating systems take into consideration the CF of RMC during evaluation of the buildings, asked for certification and how these systems look at the CF and are there some guidelines about how concrete industry can reduce their product CF?

3.2 Leadership in Energy and Environmental Design (LEED)

LEED stands for Leadership in Energy and Environmental Design. It is an internationally well known United States Green Building Rating System. It provides third party verification certificate to the buildings built on sustainable strategies and which have improved their performance across the entire sustainable development factors index. The most important factors are energy saving, water efficiency, indoor environmental quality, resources used and their environmental impacts (USGBC, 2011).

It was developed by the United States Green Building Council (USGBC) in 1998 and the first version of LEED was launched in 2000.The intent of the system was to provide an explicit framework to the building owners, contractors, designers and operators for identifying and implementing practical and measureable green building design, construction, operations and maintenance solutions.

The LEED1.0 was a pilot version and after that LEED NC2 and LEED NC2.2 were released in 2005. The NC is standing for new construction.At present, LEED consists of a suite of nine rating systems under main five categories. They are:

1. ***Green Building Design & Construction***
   - *LEED for New Construction(NC) and Major Renovations*
   - *LEED for Core & Shell Development*
   - *LEED for Schools*
   - *LEED for Retail New Construction*
   - *LEED for Healthcare (in pilot)*
2. ***Green Interior Design & Construction***
   - *LEED for Commercial Interiors*
   - *LEED for Retail Interiors*
3. ***Green Building Operations & Maintenance***
   - *LEED for Existing Buildings: Operations & Maintenance*
4. ***Green Neighbourhood Development***
   - *LEED for Neighbourhood Development*
5. ***Green Home Design and Construction***
   - *LEED for Homes*[5] *(Wikipedia,* www.usgbc.org*)*

In 2009 the USGBC launched LEED 3.0 and it is known as LEED 2009. In this version credits are assigned to all involved categories in all above written classification systems and further points are assigned to all those, based on environmental priority (LEED, 2009).

The LEED for New Construction (NC) and Major Renovationsis interesting for the commissioner company (TCG) becauseabout 40% work is for infrastructure projects and the remaining 60% is for housing/dwellings and commercial facilities (Löfgren[6], C.lab).

Table 3LEED for New Construction(NC) and Major Renovations credit category and points distribution

Credit Category	Points Available
Sustainable Sites	26
Water Efficiency	10
Energy and Atmosphere	35
Materials and Resources	14
Indoor Environmental Quality	15
Innovation and Design Process	6
Regional Priority	4
Total Core Points	110

[5]The LEED for Homes Environmental Classification System is slightly different from LEED v3, with different point categories and thresholds to make residential design more efficient (Wikipedia).
[6]IngemarLöfgren is concrete Lab Manager at TCG. Through personal communication [2011-03-15]

There are 100 base points plus an additional 6 points for Innovation in Design and 4 points for Regional Priority. For certification minimum 40 points are required and for silver, gold and platinum points range is described below (LEED, 2009).

Certified	40 - 49 points
Silver	50 - 59 points
Gold	60 - 79 points
Platinum	80 points and above

For more information on the LEED program and project certification process visit the USGBC website, www.usgbc.org.

3.2.1 LEED classification system and concrete

The study of LEED classification system showsthat the use of concrete as construction material for buildings has great potential for high LEED rating. In the following tables some suggestions are compiled, of where and how the use of concrete can give higher LEED points.

However, during reading the following written materialkeep in mind that the LEED points mentioned are in the context of whole building project. Because concrete is one of the materials used for buildings construction. This study is done just to show the potential of concrete use in order to comply with those point´s specific requirements. Later on the high lighted specific requirements, that LEED system hason concrete uses, will be applied on concrete production and composition to know if the requirements have any effect on carbon footprint (CF) of RMC or not.If they have, then to what extent?

Although the following discussion shows that the RMC has potential for high LEED rating in several LEED credit categories, but without using the right concrete composition at right place and at right time the desired results can never be achieved. To make this point more clear the possible LEED credits categories, where concrete can potentially be used, are linked to three different departments. These departments are Management, Design/Planning and Concrete producers. This division is made throughout with concrete in focus.

Definitions of some key words used in the following Table4

Management: A project manager or team of project managers belonging to different disciplines have the responsibility of the planning, execution and closing of any project.

Design/planning: A team of designers who usually developed design and suggest the sort and amount of materials used for different parts of the buildings. During the design phase if different properties of concrete (e.g. thermal, pervious) are kept in mind then a high LEED rating can be achieved through concrete construction.

Concrete production: The Company that produces concrete can have several options to improve the concrete performance.

Postconsumer material: It is defined as the waste material generated by households or by commercial facilities in their role as end-users of the products such as old building materials etc. which can no longer be used for its intended purpose.

Post industrial materials: By-products from industrial facilities such as fly ash from the coal power plantsand slag from the pig iron and steel industry.

Used abbreviations

SS: Sustainable Sites
SWD: Storm Water Design,
NC*: New construction
Dep.: Department
IEQ: Indoor Environmental Quality
ID: Innovative design
EC*: Existing Construction

Table 4: The LEED credit categories, specific concrete requirements and use function and available LEED points for respective concrete applications

Dep.	LEED category	Action	Description	%	Points
Management	Material credit -1	Building reuse	If 55% of existing building structure (in case of concrete buildings), which include structural floor and roof decking and the exterior walls and reinforcement structure, is left in place,this is worth one point and at 75-95% it is worth 2 and 3 points (ECCO, 2003).	55% and at 75-95%	1 and 2-3
	Material Credit-2	Construction waste management	If 50% to 75% by weight of existing building´s material including windows, interior walls, floor covering and ceilings is diverted from land disposal to recycle or reuse then one point is available for 50% and two for 75%. Concrete is a heavy material and easy to handle and reuse for example aggregates for road basis and construction fill. This action gives value when concrete buildings are demolished (ECCO, 2003; RMC-LEED Guide reviewed).	50% and 75%	1 and 2
	Water efficiency credit-2	Use gravel sub-base under percolate concrete pavements	The intent of this credit is to reduce the Portable water use for water landscaping and irrigation on site. This goal can be achieved by storing storm water runoff through building a basin utilizing concrete with pervious property. A study conducted by Wanielista at the University of Central Florida (Wanielista, 2007) showed that the collected water quality was approximately the same as rain water. In this case the pervious concrete was constructed on the shoulder adjacent to the parking lot. This stored water can be used for water landscaping, irrigation, washing etc. In case of no irrigation required 4 points are available (Ashley& Lemay, 2008).	50% and if no irrigation	2 and 4

Dep.	LEED category	Action	Description	%	Points
Concrete Production	Material Credit-4	Use of post consumer or Post industrial materials	To get one point the portion of post consumers or post industrial materials should be at least 5% and 10% respectively of the total value of the materials used in the whole project. Two additional points are available for 10% and 20% recycling content respectively as described above. The concrete sector has potential to achieve this value by using supplementary cementitius materials such as fly ash, silica fumes and slag cement. The other way is to use recycled aggregate as crushed aggregates instead of virgin one (ECCO, 2003; RMC-LEED Guide reviewed).	Post con. 5-10 Or Post indus 10-20	1-2
	Material Credit-5	Use local or regional materials	LEED awards one point if 20% of the materials used in the whole project are located within 800km radius of the project site. Whereas, in case of 50% content one extra point is granted. The including materials are cement, cementitius materials, concrete aggregates, concrete, reinforcement materials and wood etc. Mostly concrete aggregates and concrete plant lies within 80 to 100km radius of the project site (ECCO, 2003).	Content 20-50%	1-2

Dep.	LEED category	Action	Description	%	Points
Design / Planning	Energy and atmosphere prerequisite-2	Minimum energy performance	The energy and atmospheric category of LEED have three basic energy efficiency requirements for building to compete. For prerequisite 2, buildings must meet energy efficiency standards of ANSI/ ASHRAE/IESNA 90.1-1999 or the local energy code whichever is more stringent. For ASHRAE[7] standards see Appendix B, available at "osr.ashrae.org". By utilizing thermal heat capacity of concrete through best design practice one can meet the LEED entry requirements.	Comply Eng. Standards.	Basic
	IE Q Credit7.1	Thermal Comfort Design	By utilizing the thermal property of concrete, the requirements of ASHRAE Standard 55-2004, Thermal Comfort Conditions for Human Occupancy can be achieved. Concrete building envelop have a potential to control thermal comfort during peak situations (LEED, 2009).	Comply standards	1

[7]ASHRAE stands for American Society of Heating, Refrigerating and Air-Conditioning Engineers that develop standards and measuring methods for heating, ventilation, air conditioning and refrigeration systems through research, standards writing, publishing and continuing education to promote sustainable development (http://www.ashrae.org).

	Energy credit-1	Optimizing energy performance	Minimum energy cost saving should meet the requirements of building energy standards ANSI/ ASHRAE/IESNA 90.1-1999. The energy cost saving calculation method should be according to section -11 of these standards. This is a basic requirement of LEED and no points are available. Concrete structure with passive house design can save a lot of energy by reduction in heating requirements. Whereas in case of lower mass structure with interior insulation design energy can be saved by reducing heat demand.	15-60% NC* 5-50% EC*	1-10

Dep.	LEED category	Action	Description	%	Points
Others	ID Credit 1:	Concrete usage for Innovative Design	Concrete can play a value able role in building a sustainable innovative design because of its ability to mould in any desired shape, not addressed in the LEED 2009 for New Construction and Major Renovations Classification system (LEED, 2009).		1-5
	ID Credit 2	LEED Accredited Professional	One principle participant of the project team should be LEED accredited (LEED, 2009).		1

For more information about the credit categories and points distribution over each see Table: 1, in Appendix I or visit www.usgc.org.

3.2.2 The CF of Concrete and LEED Environmental Classification System

The study of LEED for New Construction(NC) and Major Renovations and other related research articles show that there is nothing in this system where the CF of concrete have any sort of direct link to the available points. This ECS does not incorporate CF of materials or buildings directly and even do not have any CF related information or guide.However, in some credit categories an indirect link to the CF of materials can be found. For example in material category 4 and 5 some requirements on production and use of concrete can be linked to the CF of RMC. These materials categories say that if the used concrete have 10% to 20% post industrial materials then 2 points are for the project. In the same way, use of local and regional materials is also encouragedas it also reduces the CF of concrete due to less transportation.

Even though LEED does not put any direct requirements on CF of RMC used in any building project but the requirements on use of recycled materials in concrete production will apply on concrete produced at Färdig Betong to measure difference in CF. This scenario is applied and the impact can be seen in Section 6.4.

3.3 Building Research Establishment Environmental Assessment Method (BREEAM)

BREEAM stands for the Building Research Establishment Environmental Assessment Method. It is a leading and internationally recognized systematic scheme, used for the assessment of environmental performance of buildings. About 115,000 buildings have been certified and nearly 700,000 are registered (BREEAM, 2009). It provides guidance and sets the standards for best practice in sustainable design and environmental performance of buildings in terms of energy use, ecology, water, GHG emissions, materials etc (BRMCA, 2009). It was developed in 1990 with the first two versions for sustainability assessment of offices and homes. The BREEAM manuals that are in use by construction developers and designers are mentioned below.

For the United Kingdom:

- BREEAM Courts
- BREEAM Education
- BREEAM Industrial
- BREEAM Healthcare
- BREEAM Offices
- BREEAM Retail
- BREEAM Prisons
- BREEAM Multi-residential

For international:

- BREEAM Gulf (for any building type)
- BREEAM Europe Commercial (Offices, Retail and Industrial)

BREEAM Europe Commercial: It covers the Offices, Retail and Industrial buildings categories. This includes a comprehensive plan strategy for the assessment of sustainability performance of such buildings at the design and post construction stages.

The above BREEAM versions and almost all others, account for a broad range of environmental impacts associated with:

- Management
- Health & Wellbeing
- Energy
- Transport
- Water
- Materials
- Waste
- Land Use and Ecology
- Pollution
- Innovation

Credits are awarded in each of the above areas according to performance and in reference to the criteria specified in BREEAM Europe commercial. A weighted scoring method is used to add all credits together to produce a single overall score. The BREEAM rating is determined by the following elements

1. BREEAM rating benchmarks

2. BREEAM environmental weightings
3. Minimum BREEAM standards
4. BREEAM credits for Innovation

Based on the final score a certificate is awarded and the building is rated as (BREEAM, 2009; BRMCA, 2009).

Table 5: BREEAM rating and Score percentage

BREEAM Rating	% Score
Pass	30-40
Good	45-54
Very Good	55-69
Excellent	70-84
Outstanding	85-110

For *Outstanding* some additional requirements are stated in the manual.

Table 6: BREEAM 2009 Environmental weightings

Sr. No	BREEAM Section	Weighting (%)	
		New Buildings,extensions& major refurbishments	Buildings fit-out only
1	Water	6	7
2	Materials	12.5	14
3	Transport	8	9
4	Waste	7.5	8
5	Pollution	10	11
6	Health and Wellbeing	15	17
7	Management	12	13
8	Land use and Ecology	10	N/A
9	Energy	19	21

3.3.1 BREEAM and Concrete Mixes

The commissioner company (TCG) has about 40% business in infrastructure projects while the remaining 60% is for housing/dwellings and commercial facilities (Löfgren, C.lab).Therefore, the BREEAM Europe Commercial 2009 is of concern in the following discussion. The following paragraphs are about how this ECS takes into account the CF of materials particularly RMC used in construction practices. How many points are for this category and what are the options that could be useful in reducing the CF of RMC or buildings. The study of this version and the related green guide shows that the BREEAM categories; Management, Energy, Material, Waste, Pollution, Health and Wellbeing and Water managementhave strong relation to RMC production and use.The discussion is made in the following tables on how the use of RMC can meet the categories requirements.

Table 7: BREEAM credit categories and RMC contribution

BREEAM Category	Category Issue	points	Comments	RMC Contribution
Management	Man12-LCC	2	Credits are awarded on the development of life cycle cost model of the building project. It covers the construction, operation, maintenance and end of life stage. The LCC analysis uses a study period of 25, 30 or 60 years, shown in real and discounted cash flow terms.	A long life concrete with high characteristics require low operational and maintenance cost.
Health and Wellbeing	Hea1-day lighting	1	Credits are awarded for meeting the criteria basedon a minimum average day light factor (at least 80% of the net lettable office floor area is adequately day lit).	The use of passive solar design solutions encourages the use of exposed concrete finishes that can contribute to improving day lighting and reducing need for artificial lighting (Ashley& Lemay, 2008).
	Hea5- internal and external lighting	1	Credits are awarded on best practice of lighting and building design which requires minimum lighting requirements.	Along with lighting bestdesign management plan, the use of concrete with a high illumination for external roads and pavings can contribute to lower lighting demands and comfort view (ECCO, 2003; Ashley& Lemay, 2008).
	Hea10- Thermal comfort	1	One credit is available on complying with EN ISO 7730; 2005 and two points are awarded on conductinga thermal comfort analysis.	The thermal mass properties of heavy concrete helps in maintaining the indoor temperature during peak hours. It stores heat during day (sun light) and releases on demand hence in this way it maintains a more stable, comfortable indoor environment (ECP, 2007; TCC, 2009).
Energy	Ene1-energy efficiency	15	Credits are awarded on %age improvements in buildings life cycle energy consumption. For credits verses % improvements see Table 13 of the manual.	Passive solar design using thermal mass and Insulated Concrete Framework (ICF) can maximise operational energy savings (ECP, 2007; BRMCA, 2009).
Water	Wat2- Irrigation and Wat7- carwash	1+1	Credits are awarded on reduction of portable water used for irrigation and carwash.	By using porous concrete (15-25% voids by volume of harden concrete) over the sub base of arrogates acts as filtering surface. Through designing underground water retention basin by using porous property of concrete for collecting rain water can reduce substantial amount of potable water usage. The quality of this water meets the rain water quality (Ashley, et al. 2008)

Materials	Mat1- materials specifications	4	Credits are awarded to the following building elements according to the predefined BREEAM green guide rating specification A+ to D scheme. If at least three out of fivekey elements [roof, external walls,internal walls, upperand ground floors and windows] achieve a relevantgreen guide rating of A+ to D then credits are assigned and then calculated points are added to the final score.	Different types of concrete can be used for the elements described to achieve high environmental ratings. For this admixtures and by-products from other industries, such as ground granulated blast furnace slag and fly ash can be used in concrete production.
	Mat5- Responsible sourcing	3	BREEAM has 3 points if the evidence is provided that the 80% of the environmental information of materials used in Structural Frame, Ground floor, Upper floors, Roof, External walls, Internal walls, Foundation /substructure, Staircase is responsible sourced. EMS certification, ISO 14001 andevidence about the use of waste and recycled materials are part of the assessment methodology.	The RMC producers can provide the required information to demonstrate responsible sourcing through implementing EMS (BRMCA, 2009).
Pollution	Pol1-GWP building service	1	Credits are awarded where all insulating materials in the elements (roofs, walls, floors, hot water cylinder, and cold water storage) avoid the use of substances that have a significant GWP.	The GWP is calculated on LCA bases. So the use of SCM and lower Portland cement and transport distances the RMC producers can improve their products environmental profile.

The above discussion made in the table 7 shows the potential of concrete in achieving high rating under different BREEAM categories. However, concrete producers can only have direct control in some of the categories such as Materials (Mat1 and 5), Pollution (Pol-1) Health and wellbeing etc. Table 8, as an example, shows the content of post industrial materials (e.g. slag and fly ash) and recycled aggregates in relation to the BREEAM green guide rating scheme.

Table 8: BREEAM buildings elementsrating based on the content of SCM and recycled coarse aggregates in concrete (Green Guide Rating, 2008).

Building Type	Category	Element Type	% of Slag, FA, Recycled coarse aggregate(RA)	Kg CO_2-eq (60y)/unit	Element No.	Summary Rating
Commercial	Roof construction	Flat Roof-Inverted Deck	50% slag, 20% RA	230	812530045	D
			50% slag, 20% RA	190	812530046	C
		Flat Roof-Warm Deck*	50% slag, 20% RA	150	812540074	B
			50% slag, 20% RA	160	812540075	C
	Upper Floor Construction	Flat Roof-Warm Deck**	50% slag, 20% RA	80	807280059	A
			30% FA, 20% RA	100	807280058	B
	Landscaping	Paving areas	N/A	41	824130005	A
	Under Floor Construction	Power floated	Reinforced concrete ribbed/trough slab			A+
		Power floated	50% slag, 20% RA			A
		Power floated	50% slag, reinforced concrete floor slab			B
		Power floated	30% FA, 20% RA			B
		Power floated	Reinforced concrete			C
Industrial	Roof construction	Flat Roof-Inverted Deck***	50% slag, 20% RA	240	812530045	E

*Unit: 1 m^2, U=0.16W/m^2.K (pitch) and flat 0.25W/m^2.K
**Unit: 1m^2, capable of 2.5kN/m^2 based on 7.5m column grid
*** Unit: 1 m^2, U=0.16W/m^2.K (pitch) and flat 0.25W/m^2.K

Table 9: The calculator awards points for each applicable element according to its green guide rating as follows (BREEAM, 2009).

Green Guide Rating	Points/element
A+	3
A	2
B	1
C	0.5
D	0.25
E	0

3.3.2 The CF of ready mixed concrete and the role of BREEAM EnvironmentalClassification System

The above BREEAM classification system is hard to understand, what requirements are for concrete production and how its CF profile can be improved. The study of BREEAM green guide puts forward the following options for RMC producers to improve the environmental profile of their product and to have impact on overall building rating.

- Optimising cementitious materials.
- Use of recycled or secondary aggregates.

- Optimising mass.
- Optimising transport
- Use of admixtures.
- Contacting suppliers for product specific information.

Optimising cementitious materials

About 70 to 80% (depending on the location, technology used, and transport mode) of the environmental burden of concrete production is related to the production of cement. The optimisation of cement can be done by using other cementitious materials in the production of concrete. For example use of ground granulated blast furnace slag (GGBS) and fly ash not can only reduce the environmental load of concrete but can also have some positive influences on workability and increased long-term durability of concrete when subjected to aggressive environments (Mindess, et al. 2011; Ch.5, p. 63-69). For example, One Coleman Street, UK, is a project where 30-40% fly ash partly replaced Portland cement. This was used for the whole construction and in this project a reduction of about 500 tonnes of CO_2 was achieved. (ARUP, 2011). In the UK, the share of GGBS or fly ash is typicallyabout 18% (TCC, 2009, p.8). The use of these materialsin a conscious proportion can lower the embodied CO_2 of concrete mixes by up to 40 % (TCC, 2009).

Use of recycled or secondary aggregates

The use of recycled aggregate in the concrete mixes can have impacts on the overall rating of the building but only when the recycled aggregate is resourced within the 15 km from the concrete mixing site. The recycled materials are evaluated on cost basis. If the content of recycled materials in the concrete mixes contributes at least 20% cost value of the overall material used then it comes to BREEAM credits under BS 8500 (TCC, 2009).

Optimising mass

According to the green guide methodology the environmental impact of buildings are calculated on mass basis and about 50% environmental impact of concrete buildings are because of the concrete mass. So a sufficient decrease in the mass while being maintaining the strength specification can have positive result when it comes to the rating.

For passive houses the opportunity of minimizing the mass by innovative design and using light weight fabric concrete (e.g. wood fibre) is countered intuitive and can outweigh the lower embodied impacts resulting from decreased mass.

Optimising transport

After cement, transportation of resource materials is the second largest contributing factor when assessing the environmental impact of concrete mixes (see Inventory Results section 6.4). Especially in the case of recycled aggregates it is most important to consider this otherwise it couldhave a negative impact. Thechoiceof raw materials suppliers and plant location should be considered when evaluating material suppliers and when establishing a new facility.

Use of admixtures

The use of admixtures can enhance the durability, sustainability and environmental profile of concrete. Admixtures are organic compounds and usually have high embodied CO_2 content. But as these are used in very small quantity, approximately less than 0.5% by weight, their contribution to CO_2-eq impact is small. These are used during the mixing process in order to modify the concrete properties in the plastic and/or hardened state which in turn may reduce the environmental impactof concrete by lowering the demand of cement, energy for mixing and water. The use of admixture can approximately reduce the water consumption 10 to 30% (TCC, 2009), this equates to a cement reduction of about 10 to 30 kg/m^3 of concrete.

The BREEAM classification system use LCA approach to measure CF of materials used in any sort of building project. It incorporates CO_2 at several levels of environmental performance assessment of building projects. The use of recycled materials requirements in concrete production will be applied on Färdig Betong´s products under appropriate conditions to find if it does make any difference in CF of concrete produced at the company.

The recycled materials content requirements in RMC production are applied in different ways on RMC produced at Färdig Betong and the reduction in CF of concrete per cubic meter can be seen in section Inventory Results section 6.4.

3.4 Other Related Systems

3.4.1 BASTA

This is not a certification system but a system for providing material data for products that fulfill the criteria set for BASTA which are hazardous substances that are dangerous to human health andecosystem. There is no information or requirements on climate issue (GHG emissions, energy use, resource use etc.). The substances that are evaluated during analysis are

- “Carcinogenic substances
- Mutagenic substances (cause heritable genetic damage)
- Substances toxic to reproduction (impair fertility)
- Persistent or very persistent organic substances (low degradability)
- Bio-accumulative organic substances (accumulate in tissue)
- Substances harmful to the ozone layer
- The content of lead, mercury and cadmium is regulated”

(Properties criteria – BASTA,VERSION 2011: A)

The criteria that is followed during assessment is based on the REACH Regulation (Registration, Evaluation, Authorization and limitation of Chemicals), Regulation (EC) no. 1907/2006.The BASTA-system is now a part of the Eco-cycle Council of the Swedish building since 2010 (BASTA, 2011).

3.4.2 Swedish Green Building Council (SGBC)

This was formed by thirteen Swedish companies and organizations (Academic House, DTZ, Building Owners Sweden, House Caretaker, IVL, NCC, Skanska, etc.) in 2009 but now it has over 100 registered members. It is an organization that is incharge of Green Building (in Sweden) and Miljöbyggnad (earlier MiljöklassadByggnad) and will be incharge of the Swedish version of BREEAM, established by the Building Research Establishment (BRE) UK.

All the above include energy saving, material characteristics (or resources used) and indoor environmental quality in the evaluation criteria’s. The concrete industry has a vital role in improving the environmental performance of buildings when it comes to whole life cycle of buildings. According to the Technical module of EU green building (GB) heating, cooling and lighting systems have the major impact on the energy consumption in non-residential buildings. This energy is used to maintain thermal and visual comfort (indoor climate) of the buildings. By means of improving building envelop material characteristics (Internal and external walls, floor and roof materials etc.) up to 50% energy saving can be achieved. (Lorenzo, et al. 2009, p.1).This is important in countries where a large part of the household energy is used for heating purposes, like in Sweden for example. By utilizing the thermal properties of concrete, using low cementation materials and increasing durability of its product (Ashley& Lemay, 2008), TCG can assist its customers/clients to meet the criteria and even to achieve high grades (silver, gold or A, A+....) according to the classification system.

3.4.3 Comprehensive Assessment System for Built Environment Efficiency (CASBEE)

CASBEE was developed in Japan as an assessment tool for the environmental performance of buildings. This system has passed four stages in its development. It started in 1960 and at that timeonly indoor environmental quality was in focus. Later on with increasing awareness about environment and sustainability it changed to the present form in 2005 and passed by the Japan Sustainable Building Consortium (JSBC). It measures environmental efficiency of buildings by using the following four tools based on the LCA methodology (see Figure 3) and it covers: (1) Energy efficiency, (2) Resource efficiency, (3) Local environment, (4) Indoor environment.

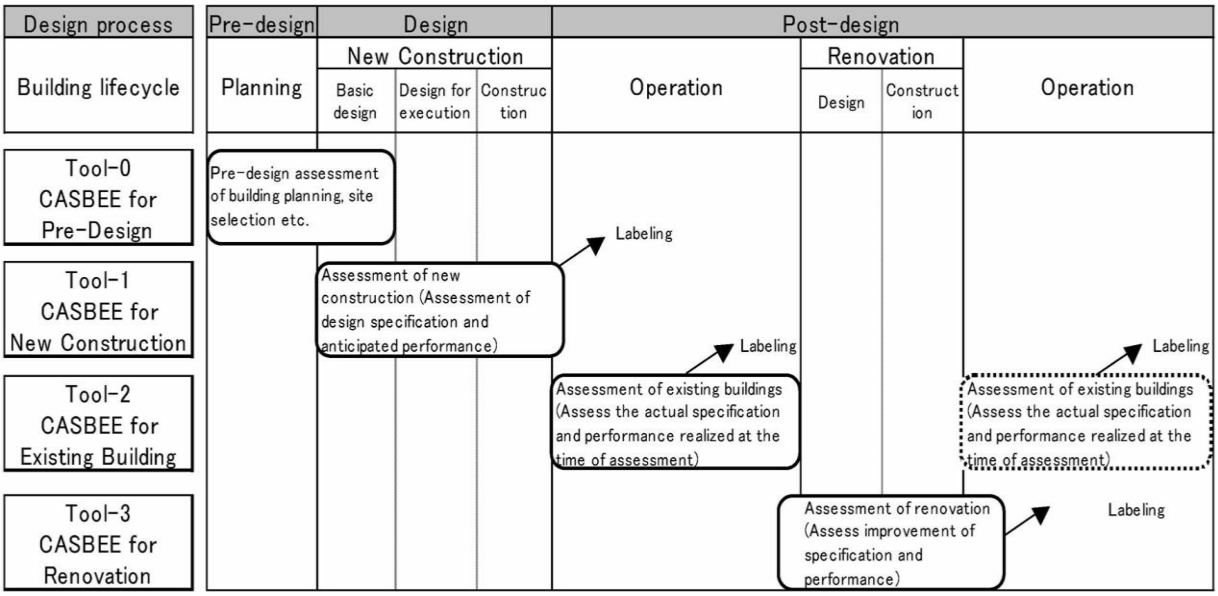


Figure 2: Building Lifecycle and Four Assessment Tools, Source: (http://IBEC:2011.jp)

The assessment criteria match LEED, BREEAM and GB to some extent but are not exactly the same (ibec.or.jp). This system is fully applied in Japan and the numbers of certified buildings are 80 according to August 14, 2009 statistics (IBEC, 2011).

4 ECS (LEED & BREEAM) and Concrete Stakeholders

This stakeholder's analysis is performed to investigate theirviews on how the Environmental Classification Systems (ECS), especially LEED and BREEAMinclude carbon footprint impact of a project, specifically RMC, and their role in sustainable construction. Moreover, the sustainability aspects of concrete as compared to otherconstruction materialsare also addressed. The future intent of this stakeholder analysis isto:

- Know the usefulness of these systems
- Develop action plan for future concrete mixes techniques
- Get information about the demand of such certification
- Get possible future potential of such schemes and relevant environmental policies

4.1 Identification of stakeholders

The identified stakeholders are presented in Figure 3. Employees at Thomas Concrete Group (TCG), environmental manager,sale manager, a production manager and a research and development coordinator, with an interest in the LEED and BREEAM systems are interviewed to know what they think about these ECS and how the TCG can work with these systems. Other internal and external stakeholders were selected with the help of company advisor and through internet.

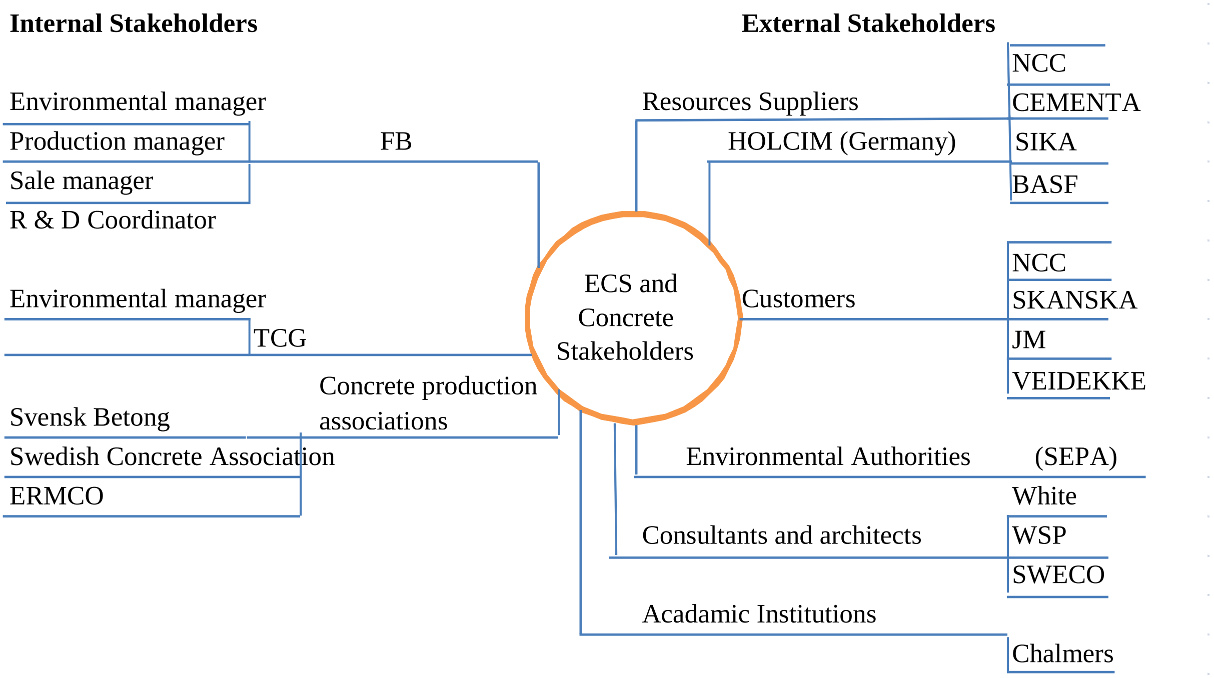


Figure 3: Internal and External Stakeholders

4.2 Interviews plan and follow up

At the first step some important stakeholders were selected for interviews and due to time constraint it was not possible to have meetings with all of the above mentioned stakeholders. In second phase some questions were prepared with the help of advisor and supervisor.

The email and some questions that were asked to most of them can be seen in Appendix II. The summaries of conducted interviews are presented below.

4.3 External stakeholders and ECS

4.3.1 Nordic Construction Company (NCC)

Nordic Construction Company (NCC) is one of the leading construction and property development companies in the Nordic region. The company is one of the important customers of concrete and also suppliesaggregates tothe commissioner company. According to the company website, in 2010 the NCC Group had sales of SEK 49 billion and had approximately 17,000 employees (NCC, 2011).

Jonny Hellman[8]is BREEAM assessor and working as environmental manager at NCC head office in Stockholm. He said the company have focus on the following three areas.

- **Energy consumption**: From start to the end of the project.
- **Materials**: All types of materials used in construction are analysed according to the BASTA standards.
- **Reduce waste**: Much effort is in reducing the waste both during the production of resources and at construction site.

The company has policy to have climate declaration or CF for building projects to show how environmental friendly the projects are. The NCC works with BREEAM and has decided all new projects be BREEAM certified. According to him there are 20 ongoing BREEAM projects. One of them is completed and three are at their last stage. With respect to concrete, he said that it is one of the large scale used materials in commercial buildings and they are trying to have a special considerationabout its environmental profile.

He said that these systems are really helpful in fulfilling the environmental obligations they have but still improvements are required. Due to third party verification these systems have potential to enhance the reliability of company´s environmental work. These are good source of communication and visualization of project and company´s environmental performance.

From future perspective, he said both systems (LEED & BREEAM) have a future and useof such systems will increase. The local versions of these systems could fast the market in the Nordic region. The presence of both is good to make further improvements but he think BREEAM will get high market share in EU countries.

[8]Jonny Hellman is Environmental manager at NCC group. Coordinate environmental issues in building projects both at strategic level and follow up. Personal Communication [2011-05-04]

According to the interviewee, concrete is a more sustainable material in term of commercial buildings because of its good thermal properties and durability. However, the market demand of LEED and BREEAM poses challenges of light weight, low cement content and use of other environmental friendly binders on concrete producers. He said the BREEAM is very open in CF and energy used. It awards credits on low CF and energy demand and these are well defined in BREEAM green guide. According to him BREEAM plays an important role in reducing the CF of concrete because it puts refined limits on use of recycle materials and renewable energy. Hence, the use of recycled or waste materials (e.g. fly ash and slag) in cement and concrete production will definitely make difference in CF of concrete and buildings as a whole in LCA view.

In future, depending on energy requirement standards, wood and glass could be active competitor of concrete, plastic materials could also be one of them.

So far in Sweden the market of LEED and BREEAM certified buildings are low and very few investors are willing to pay a bit extra money for such projects. However, in future such certified buildings might have higher economic value as compare to noncertified ones.

4.3.2 SKANSKA

Skanska was founded in 1887 and now is one of the world largest and leading international project development and construction companies. It develops offices, homes and public-private partnership projects. It ranked in the world's ten largest construction companies, with 52,000 employees in Europe, the US and Latin America and had revenue 122 SEK billion in 2010. (SKANSKA, 2011).

Emil Anderson[9] says that the company has a group of environmental engineers with competency both in LEED and BREEAM. But the company has more work with LEED projects.

He said that both systems are pretty much similar and helpful in fulfilling the environmental obligation they/Skanska have. But sometimes it feels very dim to just bind toone such system as it varies project to project. It is hard to say which one is better to lead the construction sector onto asustainable track. However, at least these systems are helping to improve the environmental work in construction. As a whole, the BREEAM seems to be more effective in the EU as compare to LEED. But the LEED version 2012 will hopefully be more efficient and also incorporate CF of buildings.

After the new version of LEED and with the local versions of both systems it might bean increased market demand of such certified buildings in EU. It might be true to say that with the increased environmental interest of people/society and more strict environmental regulations it will automatically push the construction companies to look at their supply chain. So at least the concrete produces should look at their resources and concrete production processes. There is a need of special care about the use of cement and other

[9]Emil Anderson is an Environmental certification engineer and a LEED assessor person. He is responsible of correct documentation throughout the stream line of projects at SKANSKA. Personal communication [26 April 2011]

binders to make and show that the concrete is more sustainable as compare to wood and steel. The concrete industry definitely can do this.

On a question about the economic value of certified buildings he replied that the real estate companies are looking at how they can get higher value of such buildings. But it is hard for them to claim that a certified building is more sustainable as compared to other.

4.3.3 Veidekke

The Veidekke was founded in 1936. It is one of the Scandinavia's largest contractors and property developers,with itshead office in Oslo. It had a turnover of NOK 15.6 billion in 2009 with approximately 6,000 employees (Veidekke, 2011).

Johan Alte[10] was not familiar with LEED and BREEAM but at least had some knowledge about them. He said that these systems (LEED and BREEAM) are helpful in meeting the environmental obligations that he/Veidekkehave. For him these systems talk a lot about commercial buildings but not that much about small scale residential ones.

About the future role of these he said it is hard to say anything because with increasing environmental information more and more certification systems and standards are coming. But it would be better if they had one or maximum two such systems to work with properly instead of a large number.

In his view, commercial buildings made out of concrete are more durable and cheap as compared to other materials such as wood; glass etc. He had no idea about which material is more environmental friendly because of reliability issues about environmental data published by different companies. However,reliable environmental information from the supplier companies can help the construction sector to make a real change in construction practice.

According to his view wood has potential to be a strong competitor to concrete in construction sector. But research in nano field might come up with some other materials.

4.3.4 Sika, RMC admixtures supplier

Niklas Johansson[11]was not familiar to LEED and BREEAM. However, he talked from a sustainability point of view. He said, the Sika products are mostly oil based and in near future they might have problems both from environmental regulations and resources for admixtures production due to tough environmental regulations and high oil prices respectively. Hence, concrete admixtures companies are looking for alternative resources that would might be helpful to improve the ready mix-concrete environmental profile indirectly.

At present his company following BASTA and REACH environmental systems to show the environmental performance of the products. He said, recently the emissions from transport of admixtures to the customers and leakage of chemicals from concrete material after demolition

[10] A business developer at VEIDEKKE Goteborg, Sweden, Responsible for quality work and to get the employees understand environment importance. Personal communication [27 April 2011]
[11] Product manager concrete admixtures, SikaSverige AB, Goteborg, Personal communication [2011-04-26]

of buildings are the most prioritised ones and work for improvements in these fields are going on.

4.3.5 White

White is an architectural consultant company having business in different parts of Europe. It was established in 1951 by Sidney White**.** It provides services in almost all types of construction such as Residential, Construction maintenance, Design, Shopping, Interior design, Office & Industry, Culture & Leisure, Landscape, Environment and Project management etc (White, 2011).

KaterinaTulina[12]had not detailed experienced with the LEED and BREEAM but have knowledge about these. She thought that these environmental classification systems will be more and more in the market until the new EU directive on climate change comes. However, after the new directive what will be new, is hard to say now.

She said that these systems help in finding the new ways of environmental improvements and makes it easier to meet the environmental demands of several projects in a systematic way. According to her, BREEAM has higher potential for Nordic countries as compared to LEED. But with the new LEED and BREEAM in home languages they might have equal market shares.

These systems will lead the construction industry towards more sustainable direction because these look for recycling and reuse of buildings and building materials. This is the way which can also bring improvements in CF reduction of buildings and indirectly in RMC. While the other green building systems such as EUGB system does not say anything about such options. Furthermore, the concrete industry should focus on lower energy and virgin materials consumption from a system perspective. She has not been involved in any LEED or BREEAM project so could not say about the role of these systems and CF concrete particularly.

She did not give any comment about market competitors of concrete in construction sector. According to her experience only a few number of international clients are willing to pay little bit more for eco-energy projects.

4.3.6 WSP

WSP is one of the leading engineering and design consultant companies in the world. It operates globally with more than 9,000 employees and has permanent offices in 35 countries. The group provides services with expertise in four main areas Property, Energy and Environment, Transport infrastructure and Management and Industry (WSP, 2010).

ThereseMalm[13] said that these systems are really helpful in fulfilling the environmental obligations WSP/she has. To work with these is easy because they are developed in a

[12]KaterinaTulina is a Civil Engineer usually involved in LEED and BREEAM certification projects but mostly works on energy efficiency of buildings. Personal communication [2nd May 2011]

[13]Malm is a LEED assessor and works with environmental hazards and property due diligency before selling to the clients at WSP Goteborg, Sweden. Personal communication [18th April 2011]

systematic way and act as a tool for her to check the environmental performance of a project. These systems are good and have potential for sustainable development. To work with both systems is better, as it facilitates improvements in these and for any such systems.

According to her, it is much easier to get higher points in Sweden for LEED as compare to BREEAM. LEED does not consider aspects of hazardous properties in materials used in construction such as fly ashbut BREEAM consider this. She was not sure about the BREEAM but she said that LEED does not say anything about the CF of a building or any sort of construction project.

At present the BREEAM is more accepted in Sweden as compare to LEED. But the new version of LEED is expected be more strict and will meet the Swedish environment regulations demands. If such happened then both the systems could have a bright future in the Nordic countries as well.

Concrete is a good construction material but there is a need to reduce virgin resource and energy used. The concrete industry should work to make concrete lighter and with better thermal insulation. By improving the life cycle environmental performance and establishing transparent environmental inventory data of concrete the industry can help a lot to achieve higher points for certification.

For some clients/owners certified buildings have higher values because they know what this means.

4.3.7 Chalmers University of Technology

Barbara Rubino[14]stated that these systems are just a check list which could prevent the architectural engineers to work with innovativesolutions. But on the other hand to work with such systems is good especially for multinational consultant and construction companies because at least they will get aware of some important environmental issues.

Both LEED and BREEAM need improvements to make them adoptable for individual home conditions and a continuous system of improvement is required. She said that such systems are only for commercial projects and not applicable for small firms and at small level projects.

According to her, Chalmers is working on a new building sustainability performance model,which is going to use a different approach to measure the sustainable performance of buildings and building sector itself.

She said that the concrete industry needs to focus on lighter and stronger materials to reduce materials and energy flows. For this the use of woollen and plastic fibers could be an option.

[14]Barbara Rubino is a Senior lecturer at Architectural department of Chalmers University of Technology Goteborg, Sweden. Personal communication [27th April 2011]

4.4 Internal Stakeholders and ECS

4.4.1 Thomas Concrete Group AB (TCG)

AnnikeAndreasson[15] knows about the LEED and BREEAM especially from the group business perspective. She has not been practically involved in any sort of LEED or BREEAM project so far. The TCG is working with ISO 14000 series of environmental management systems but to work with the LEED and BREEAM is the need of present because of customers demand, she realized.

She thinks that the demand of such ECS would increase in future with more strict environmental performance requirements. These ECS are good for sustainable development because they engage and provide continuous opportunities to look outside the system. One single ECS for all with continues cycle of improvements would be much better and easy to work instead of many.

There is a need to work much more in the field of educating the employees, customers and society about the real value of working with environmental requirements. She said many of us accept that to work with environment is better but not all are ready to apply this on ourselves. Therefore, it's the call for time to come up with scientific and practical proofs to realize the investors that working towards sustainable development is real economic saving instead of extra cost.

4.4.2 Färdig Betong AB

Curt-Arne Carlsson[16]has not as such any environmental responsibility but is trying to incorporate this knowledge as an important key factor in business development area. He knows about the LEED and BREEAM but is not too familiar with these. He is well aware about what requirements these systems haveon concrete producers.

These systems are the future and can play an important role to push the construction sector on the sustainable development track. In his view, Färdig Betong should work with these ECS becausesome of the most important contractors have introduced in their policies to work with LEED and BREEAM, for example SKANSKA is working with LEED while NCC with BREEAM. Hence, to keep itself in the concrete business market the company must modify its production process.

According to him, the ECS are good for sustainable development because they force to recycle and reuse the construction materials. Further, the carbon footprint tool will also help the company to look at and communicate the environmental benefits in concrete production according to the LEED and BREEAM or any other such system.

[15]AnnikeAndreasson is Environmental Manager at TCG and responsible of co-coordinating environmental work with in TCG, training employees and making sure that the company is complying with environmental regulations.

[16]Curt-Arne Carlssonis business development manager at Färdig Betong.

4.5 Conclusion from Stakeholder´s views

It is difficult to come up with an efficient conclusion because of the relatively few stakeholders that could interview but also time limitation played apart. However, based on the gathered information the concrete industry should;

- Have reliable and transparent life cycle environmental data onconcrete production
- Focus on lowering the cement content
- Increase the use of supplementary cementitious materials in an effective way
- Focus on the production of stronger, lighter and thermal insulating concrete

Almost all the external stakeholders said that increasing environmental information will introduce strict environmental regulations. LEED and BREEAM and such other environmental classification systems will be more and more usedin future. They think that the concrete industry should ready to assist the construction companies to meet such demand. The concrete industry need to analyse its resource supply chain and focus on local, renewable energy and materials resources.

However, many of them emphasised on use of supplementary cementitious materials in concrete production to reduce CF impact. The study of LEED and BREEAM points out that increase the content of post industrial and post consumers materials (as defined in Chp.3) in cement and concrete industry will not only lower the CF but will also reduce the demand of virgin materials.

To see the difference in CF of concrete with recycled materials contentas defined in LEED and BREEAM go to the chapter Inventory Results of this report.

A few of the interviewees had knowledge about how LEED and BREEAM deal with CF impact of buildings. Based on their views, it is only the BREEAM that incorporate this environmental impact and awards credits on reduction that could be seen in *BREEAM and CF of concrete* heading in the previous chapter.

5 Carbon Foot-print Methodologies

The Carbon footprint, climate footprint, GHGs emissions footprint and such others are the most commonly used terms to express the impact of society´s every day activities on earth´s climate. The term CF is used to express the total amount of GHGs emissions over the life time of products, services, organizations, society and even individuals (Carbon trust, 2011)

The term 'greenhouse gases' represents a group of gases present in the atmosphere which absorb the radiation from the sun (shorter wave length) and emit them within the thermal infrared range (longer wave length). These gases influencethe temperature balance between the earth and the atmosphere significantly;the United Nations stated that, during the last century the climate temperature has increased about 0.6 degrees Celsius and more global warming is expected in coming decades (Global warming, 2011).

As an example some GHGs, their life time range and their Global Warming Potential (GWP) over 100 years is presented in Table 10. Although a full list of GHGs, their life time and GWP coefficients presented by the IPCC, "*Working Group I report: The Physical Science Basis of Climate Change:2008"*,is in appendix III. However, the most common greenhouse gases that are considered most affective in the Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, ozone and CFCs.

Table 10: Global Warming Potential (GWP) of major GHGs (IPCC: 2007)

Gas	Chemical formula	Life time(years)	$GWP_{100years}$
Carbon dioxide	CO_2	50-200	1
Methane	CH_4	12	21
Nitrous Oxide	N_2O	114	298
Chlorofluorocarbons	CFCs	45-1700	4750-14400
Hydro-chlorofluorocarbons	HCFCs	1.3-17.9	77-2310
Hydro-fluorocarbons	HFCs	1.4-270	437-12000
Sulphur hexafluoride	SF_6	3200	22800
Per-fluorocarbons	PFCs	740-50000	7390-177700

Global warming potential is an approximation of how much a given mass of any one of the greenhouse gases will contribute to the global warming impact. The GWP of each GHG is calculated through multiplying by its given mass with its respective GWP coefficient given by the IPCC over a specific assessment period (Wikipedia, 10 June 2011).

A large number of standards or methodologies, based on the LCA tool, have been developed to calculate CF of products, services, individuals,and society and organization´s activities. Some are recognized and followed internationally such as PAS 2050, EPD, the GHG protocol, ISO14000 series standards etc (Baumann, et al. 2004).

5.1 CO_2-equivilent

The Carbon dioxide equivalent (CO_2-eq) is used as a standard unit to measure and report total warming effect of all different GHGs. This is measured by multiplying the mass of non CO_2 GHG withits GWP factor. For example the CO_2-eq GWP of CH4 is 21.

This term has slightly different interpretation in the context of *emissions* and *atmospheric concentrations* of greenhouse gases.

However, in the context of *atmospheric concentrations* of greenhouse gases, the term "CO_2-eq" is described from two different perspectives:

- According to Stern (2007) it is the concentration of carbon dioxide that would give the same warming effect as the collective effect of the entire greenhouse gases in the atmosphere. This approach does not consider the cooling effect of aerosols (Stern, 2007.chp.7).
- Some authors define it in terms of radiative forcing which refers the net forcing of all anthropogenic radiative forcing age
- nts including GHGs, tropospheric ozone, and aerosols. The cooling effects of aerosols are considered but natural forcing are not (see e.g. Elzen, et al. 2006)

5.2 Product carbon footprint (PCF)

A product carbon footprint computes all sorts of the greenhouse gas emissions connected to the whole life cycle of a product. The life cycle stages include:

- Extraction, production/processing and transportation of raw/ resource materials
- Manufacture or service provision
- Distribution
- End-use
- Disposal/recycling

The sources of GHGs at each stage could be energy use, transportation fuel, and refrigerant losses from air conditioning sources, waste handling and disposal. In case of a service product CF is defined as the GHGs emissions over its service time (Carbon trust, 2011).

5.3 Carbon Footprint Schemes / Methodologies

The carbon footprint (CF) calculation and its documentation need to be transparent, reproductive and reliable. There for, the right and more appropriate choice of CF methodology, based on the objectives,are vital to make results more reliable and trustworthy.

There are two ways of method selection for CF of a product. One is to develop your own method in consistence some basic standards (e.g. ISO standards) and the other one is to use one from pre-existing methods. At present, mostly used and well recognized methodologies or standards are

- ISO Standards
- GHG protocol initiative
- Publically available specification (PAS) 2050

- Environmental Product Declarations (EPDs)

These are all based on the LCA approach whencome to CF of products. The ISO standards series and EPD are described briefly because ISO standards are more about environmental management, performance, auditing and basic principles of LCA. While EPD mostly rely on Product Category Rules (PCRs) for different methodological issues e.g. system boundaries. However, the PAS-2050 and GHG protocol initiative (Product Life CycleAccounting and Reporting Standard 2009) are discussed in more detail.

Below some important features of concrete produced at Färdig Betong are highlighted. Theseaspects are very important to consider in CF methodology selection process.

5.4 Important features of Concrete produced at Färdig Betong (FB)

The selection of CF methodology for the calculation of concrete CF will be based on the applicability and compatibility of product produced at Färdig Betong, which is of concern in this thesis, is concrete mixes. The practical applications of thesis results would also be keptin mind.

- **Concrete mixes composition changes relative to end use and customer demand**

According to IngemarLöfgren (R&D director, TCG C.lab) there can be more than 200 recipes for concrete production at one plant. The type of recipe depends on the end use and exposure environment. This means different content of cementitious materials, aggregate size, and admixtures.In addition, different plant set-ups affect the energy used through the supply chain. To be able to calculate CF of concrete produced at FB all recipes are merged into five main types which covers almost 80 to 90% of all types of concrete produced at the company.

- **One of the input materials has large environmental impacts compared to others**

The cement is one of the main input materials and which has a high environmental impact profile as compare to other materials. This has been shown by many CF of concrete and LCA of buildings studies such as (Nilsson, et al. 2009& 2010; Kjellsen, 2005; Nielsen, 2008).

- **Use of waste of some others processes as input material instead of virgin one**

In many concrete products fly ash, which is a waste material of coal power plants, and blast furnace slag, that is a waste of steel and iron industry,can be used as cementitious materials. The content of these materials has noteworthy impact on CF profile of concrete.

- **Different end use phases**

The concrete produced at FB is used for different purposes such as roads, bridges, buildings etc. However, the transportation to the end use site has contribution to CF but it mostly depends on the mode of transport and distance. Note that the userphase is not the part of this thesis.

- **Long life of end use product**

The buildings and bridges usually have a long life ranging 60 to 100 years. During this long life concrete does not have a climate impact; rather it actually absorbs CO_2 from the environment through a process called carbonation. *In countries with the most favourable recycling practice it is realistic to assume that 86 % of the concrete is carbonated after 100 years, taking up approximately 57 % of the CO2 emitted during the calcining process* (Nilsson & Fridh, 2010).The use phase is not in concern of this project.

- **Recyclable product**

A large portion of concrete construction is recyclable and can be used for different functions. For example, the coarse aggregate after crushing can be reused for concrete mixes and other waste is more beneficial to use as base materials during roads and building construction (European Concrete Platform ASBL, 2009).

- **The intent of CF study**

Färdig Betong wants to be able to communicate the GHG emissions connected to concrete production (cradle-to-gate) to interested customers but mainly for internal (within TCG) communication. And the other objective is to know CF associated to different concrete recipes.

5.5 Available product Carbon Footprint methodologies

There are several CF methodologies based on LCA thinking approach. From the literature review and studiesconducted atChalmers it is found that the mostly accepted and widelyused standards for CF of products are

- ISO 14000 series standards
- Environmental product declaration (EPD)
- Publically available standards 2050 (PAS2050)
- Greenhouse gas protocol initiative (GHG protocol Initiative: Product Life Cycle Accounting and Reporting standards)

These methods provideslightly different standard approach for life cycle CF calculations of products at different levels. The methodological approach of these standards can be grouped into three different category levels based on their appropriateness for CF calculation.

- Organizational Level
- Project level
- Product level

In the following chapter; ISO, PAS2050 and GHG protocol initiative are described and their approach on different LCA methodology issues is discussed.

5.6 ISO standards

The ISO 14000 is a series of environmental standards that assist organizations, companies and individuals to look at environmental impacts associated with their work environment, production process and products over whole life span. This standard series also provide guidance on how one can reduce environmental impacts and work with environmental regulations. This ISO series is classified as

Environmental Management Systems:	14001, 14002, 14004
Environmental Auditing:	14010, 14011, 14012
Environmental performance evaluation:	14031
Environmental labelling:	14020, 14021, 14022, 14023, 14024, 14025
LCA	14040, 14041, 14042, 14043, 14044
GHG	14064; 1-3

Based on the objective of this master thesis, the most relevant ISO standards are LCA ISO 14040 series standards.

LCA; ISO 14040 series

The ISO14040 series standards are considered as basic documents for any type of LCA study. These standards described basic principles, procedure and framework of LCA.

ISO 14040; described principles and framework
ISO 14041; give information on goal and scope and inventory analysis
ISO 14042; talks about environmental impacts assessment and evaluation
ISO 14043; Provide information on how LCA results should be presented
ISO 14044; specified requirements and present some guide lines on different phases of LCA such as preparation, data types, critical review and some other methodological issues (Elcock, 2007)

The study of this series of ISO standards shows that at many places interpretation is inadequate such as ISO standard does not recognise choice of allocation base on the purpose (accounting or change-oriented) of study (Baumann, et al. 2004). So these standards are not going to be discussed further, but will be consulted as basis for LCA of concrete.

5.7 Publically Available Specifications 2050

Publically Available Specifications 2050 (PAS 2050) has been developed by the British Standards Institution (BSI) in response of a large scale community and industry groups desire to have a consistent method for the calculation of GHG associate to the life cycle (LC) of products and services. This project was sponsored by Defra and CorbanTrust (PAS, 2008). It is not a standard but rather a method which provide a detailed base for the calculation of CF of products. It was developed onthe basis of existing LCA methods; BS EN ISO 14040 and BS EN ISO 14044 with some additional specific requirements for LC GHG of goods and services.

This methodology can be used for any type of product; Business-to-Business (B2B) and Business-to-Consumers (B2C). On a very general level, not specific to a certain products or sector, it provides detail on how to conduct a life cycle inventory of greenhouse gases associated to the LC of a product or service. It does not include product category rules although, refer to use if any available and developed in accordance to BS ISO 14025 (PAS, 2008).

5.7.1 PAS 2050 and LCA methodological Issues

Functional Unit

In any type of LCA study the functional unit is ambiguous and it must have to be clearly defined. It should serve as a reference unit for all inputs and outputs streams of the system under study and potential environmental impacts. The PASprefers large functional unit (i.e. one tonne) which should be derived by examine how the product is typically consumed.

Greenhouse gases (GHG)

All GHG listed in IPCC 2007 reports shall be calculated in a carbon footprint (CF) study. The global warming potential (GWP) of all GHG shall be presented as CO_2-eq and weighed up based on the IPCC latest GWP coefficients with a time perspective of 100 years. The emissions from the use phase are also considered as released in the beginning of 100 years period. However, if the emissions from the use phase are not considered as released during the assessment period then a factor of time can also be applied and the calculation method is illustrated in *guide to PAS 2008*. The calculation is not a problem itself but asses the right time when emissions from the use phase might occur is problematic.

The emissions arising from the provisioning functionssuch as growing, harvesting and transporting of renewable fuels (e.g. bio-fuel) shall be included while the CO_2 emissions from the biogenic carbon of the fuels shall be excluded. It is limited to the use of renewable energy carriers.

Allocation Methods

In PAS allocation method is described in three different cases.

- Multi-output
- Multi-inputs
- Recycling

In the first case,PAS suggest that the process is divided into sub processes and all possible data for individuals is collected.

In case of Multi-output, PAS refers to two options for computation of GHG emissions, namely: System expansion and Economic value base.

For recycling content in the input materials PAS advise two options.

i. Recycling content originating from the same product system; In this case emissions shall be calculated on content (weight or volume) basis.
ii. In case of recycling content originating from out of the system or process, PAS directs BS EN ISO14044: 2006, 4.3.

CO_2 Storage

In case of non-living products such as concrete, CO_2uptake from the atmosphere shall be included in the GHG impact assessment over a 100 years impact assessment period. The method for computing weighted average carbon storage impact is described in Annex C of PAS2008 report. The equation is;

$$\boldsymbol{Weighting\ factor} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{100}} \boldsymbol{X_i}/100$$

Where
i= each year in which storage occurs
X_i=the proportion of total storage remaining in any year i.

Land use changes

According to the PAS 2008 the effect of GHG from a direct land use change is included in the CF life cycle of a product.The direct land use change means the conversion of non agriculture land to agricultural or for any other type of input material for the product of concern. Whereas, indirect land use changes are excluded.

Off setting

This mechanism is not included in LC greenhouse gas accounting and reporting of a product in PAS methodology. It states that the changes in GHG emissions arising from use phase due to operations or application of an alternative shall be excluded from the LC greenhouse gas accounting and reporting of a product.

System boundaries

If the product of concern is in product category rules (PCRs) developed in accordance with BS EN ISO 14025, then PAS refers to establish the same system boundary as described in PCRs of the same.

However, if PCRs do not exist for that product then system boundary should be:

Raw material: All sort of GHG emissions associated with production, processing, transportation of raw materials shall be included in the accounting.

Energy: The emissions associated with the provision and use phases of energy in the LC of a product shall be accounted. It states that the emissions arising from the point of energy resources (coal, oil, gas bio-fuels etc.) extraction to end use shall also be the part of LCI of a product.

Capital goods: The emissions arising from the production of capital goods are not included in the PAS 2050.

Operations within the premises of production process: The emissions arising from supporting or provisioning functions within the premises of product manufacturing operations such as emissions from lighting, cooling, heating ventilation etc. are included in the CF life cycle inventory of product.

Storage: The emissionsfrom storage or storage operations of resource materials and products shall be included.

Use phase and disposal: The GHG emissions from the use and final disposal phases over a 100 years assessment period shall be part of inventory. However, in case of B2B product such as concrete emissions from use and final disposal are excluded in PAS methodology.

Cut off criteria: The user of PAS 2050 shall include GHG arising from all material sources life cycle phases except from the use phase. It defines material sources as, the sources exceeding 1% of anticipated GHG emissions connected to LC of the product. Altogether, 95% of anticipated GHG emissions must be covered. However, PAS 2050 explicitly excluded GHG emissions associated with;

- Human feeding and their energy input to some processes
- Transport activities of consumers and employees to and from the work place
- Transport by animals
- Manufacturing of machinery used and others

Data Requirements

Data should consist of all GHG occurring within the system boundary of the product. It should be updated from time, technology and geographical perspective and be accurate and transparent. Primary data is required from the operations owned, controlled or operated directly by the organization implementing PAS.In case of upstream processes, if the organization or company has more than 10% control on that then primary data shall be used. But where company does not havecontrol and data is lacking then the most relevant secondary data is acceptable.

Validity of analysis

If no change occurred in the studied system over two years then results would be valid for 2 years. In case of any significant change validity period could end before 2 years.

Verification: The PAS 2050 allows three types of verifications for claim.

Independent third party verification:In this case an accredited 3rd party verify that all calculations are being done in accordance with PAS methodology.

Other party verification: It means that any normative third party can verify that calculations are correct and in reference with PAS requirements.

*Self declaration:*The organization implementing PAS can verifyits results itself. But in this case the organization has to prepare a supporting document in reference to BS EN ISO 14021 requirements.

Communication and reporting: PAS 2050 does not provide any specific requirements for communication and reporting of LCA results.

5.8 Greenhouse gas Protocol Initiative

The greenhouse gas protocol initiative is a joint venture of World Resource Institute (WRI) and World Business Council for Sustainable Development (WBCSD) which develops internationally recognized standards for GHG accounting and reporting. This project was supported by over 200 companies internationally including governments, non-governmental organizations, universities and research institutes. From this platform, standards are usually published after consensus from all stakeholders involved. Its mission is to develop internationally accepted standards for GHG accounting and reporting and to promote their adaptation.

The GHG protocol initiative comprises two types but interlinked standards that are

i. The GHG protocol accounting and reporting standards (this document provides a step-by-step approach for companies to use in quantifying and reporting their GHG emissions)
ii. The GHG project quantification standards (a guide for quantifying reductions from GHG mitigation projects)

5.8.1 The GHG protocol accounting and reporting standards

These consistof guidelines; principles and standard methodology for companies willing to establish their GHG inventories. The GHG protocol accounting and reporting standards are known as GHG protocol and this term will use in the following text. The term companies represents all sort of businesses ranging from government, nongovernmental organization, academic institutions, single unit company to large business having number of companies. These standards cover only the GHG listed in Kyoto protocol; CH_4, N_2O, HFCs, PFCs and SF_6 (GHG protocol, 2004)

5.8.2 The GHG protocol for project accounting

It is a policy neutral tool has been developed to quantify benefits brought by the projects aiming to reduce GHG emissions to mitigate climate changes. It is also serves as a basic document for the development of new appropriate standards to create GHG market worldwide.

5.8.3 The GHG protocol Initiative: Product life Cycle Accounting and Reporting Standards

So far, the GHG protocol initiative has developed the following GHG standards since its beginning in1998.

- GHG Protocol Corporate Accounting and Reporting Standard (2004)
- GHG Protocol for Project Accounting (2005)
- GHG Protocol Land Use, Land-Use Change and Forestry Guidance for GHG ProjectAccounting (2006)

- GHG Protocol Guidelines for Quantifying GHG Reductions from Grid-Connected Electricity Projects (2007)
- Product life cycle accounting and reporting (2008)
- Corporate scope 3 (value chain) accounting and reporting (2008)

(Adopted from Product Life Cycle Accounting and Reporting Standard 2009)

In this master thesis "the product Life Cycle Accounting and Reporting Standards" developed in 2008 and reviewed draft published in 2009 is discussed. In the following text,the discussion is carried out from this standards perspective. As this study is just focusing only on a single product (concrete) and a single climate issue CF, this standard seems to be appropriate for comparative discussion from LCA methodological issues to look at its applicability for concrete CF. In the following discussion the GHG product life cycle accounting and reporting standard will be written as PLC A&R (product life cycle accounting and reporting).

5.9 The GHG Product Life Cycle Accounting & Reporting Standards and LCA Methodological Issues

The following five accounting principlesare intended to underpin all aspects of GHG accounting and reporting for products as the other standards too.

i) Relevance ii) Completenessiii) Consistency iv)Transparencyv) Accuracy

<u>Functional Unit (F.U)</u>

The functional unit is a normative requirement and some discussion is also done in the document on functional unit establishment. The F.U. shall be a representative of all types of system flows and be inconsistent with goal of the study.

<u>System boundary</u>

According to the definition of GHG protocol for PLC A&R standard, a clear map (flow chart) of a product life cycle including all activities, from its raw materials acquisition to final disposal and waste handling, shall be established as product system boundary. In case of partial inventory (cradle-to gate) end of life cycle and recycling shall not be included.

Temporal boundary: The accounted GHG shall be based on the product life span. In case of uncertainty in product life time, the organization implementing the PLC A&R standard shall assume a 100 years temporal boundary. It means that all GHG emissions shall be accounted and reported over a 100 years' time period.

Capital goods: These shall be accounted if the emissions are significant.

Facility operations: The operations thatthat contribute to energy and material used at the production facility and released GHG shall be accounted.

Official activities: The GHG emissions from the corporate (e.g. TCG AB) official activities such as Personnel, Financial Accounting, Information Systems Management, Marketing, Research and Development, Headquarters´ activities and Travel etc. shall be part of inventory if the effect is significant.

Land use changes: The emissions due to change in carbon stock of soil either in direct or indirect way shall be included in the LCI. In case of barren or rock land this effect is not included.

Carbon storage: The carbon storage potential of a product is not included but can be reported separately.

Data collection

The standard requires primary data for all foreground processes[17] and some significant background processes[18]. The secondary data should be an average of various similar processes to increase confidentiality. For activities where neither primary nor secondary data is available then proxy data could be used under some best approximation to fill the data gap.

GHG emissions

The GHG protocol defined all greenhouse gases and data required in three different scopes.

Scope-1: Refers to the GHG emissions from all the processes that are owned or under directcontrol of organization implementing this standard. Only the Kyoto protocol GHGs are covered in this methodology. The other GHG such as CFCs, N_2O etc. included in IPCC but not in Kyoto protocol could be mentioned separately.

[17]Processes that are directly connected over the product‘s life cycle by material or energy flows, from extraction and pre-processing of product components through to the product‘s end-of-life (GHG protocol).
[18]Processes that are not directly connected to the product or its components Background processes include facility operations, corporate activities, and capital goods.

Scope-2: Indicate GHG come from the production of purchased electricity used in the company.

Scope-3: Indicate emissions from the foreground processes not in direct control of company such as raw materials acquisition, processing and transporting etc.

Allocation

This method is very well explained in this standard. It advises where ever possible allocation should be avoided. Where it is unavoidable, the method should be selected in the following preference order.

- Process subdivision
- System expansion
- Physical allocation factors
- Substitution
- Market value
- etc

Reporting and communication

This standard required a specific format on communication and reporting.

Validity

The studied results would be valid until a significant change occurred in within the selected system boundary.

Certification

In order to claim compliance with standard two types of certification is authorized.

Self assurance: A person or team which have not been a part of project team could conduct review and certify compliance to standards.

External certification: An accredited external party can award compliance certificate after conducting verification according to the ISAE3000 or ISO 14065 standards.

5.10 Comparative Analysis of PAS 2050 and the GHG Product life cycle Accounting and Reporting Standards

Table 11: Comparison of CF Methodologies (PAS 2050 & GHG PLC A&R) in relation to LCA Methodological Issues

Methodological issues	Product LCA Methods / Standards	
	PAS 2050	The GHG Protocol Initiative Product Life Cycle Accounting and Reporting Standard
LCA	Required	Required
LCA stage	Cradle-to-grave , Cradle-to-gate	Cradle-to-grave, Cradle-to-gate
Impact category	Single issue; Carbon footprint	Single issue; Carbon footprint
GHG	GHG listed by the IPCC	GHG listed by the Kyoto protocol
Functional Unit	Must be defined	Must be clearly defined
System Boundary		
Anticipated LC data	Combination of primary and secondary data	Primary, secondary and proxy data
Immaterial Contribution	Material sources contributing more than 1% to the total anticipated GHG emissions included	Cut of criteria is rejected; all sort of emissions shall be included
Raw material	Emissions from energy and materials from acquisition, processing and transporting	Emissions from energy and materials from acquisition, processing and transporting
Energy	Emissions from the provision of energy included	Emissions from the provision of energy included
Capital Goods GHGs	Excluded	Included
Emissions from the operations in premises	Production unit, offices, warehouse activities (lighting, cooling, transporting etc.)	Production unit, offices, warehouse activities (lighting, cooling, transporting etc.)
Emissions from the manufacturing	Included in details	Included in details and cover whole organization
Transport	Averages accepted Transport of fuels included	Site specific, self measured data is recommended, all sort of transp. included
Storage emissions	Included	Included
Emissions from waste disposal	Included; in case of cradle-to-grave	Included; in case of cradle-to-grave
Employees transport	Excluded	Included
Offset	Does not allow	Not mentioned
Land use changes	Mentioned in details	Mentioned in details
Recycling	Two types Open loop Closed loop	Closed-loop recycling De-facto closed loop recycling Open-loop recycling Others
Allocation	Subdivision, System expansion, Economic	Subdivision, system expansion, physical allocation factors, substitution, economic value and others
Data Quality		
Primary Activities data	Processes owned, controlled and operated by company	Required from processes owned, controlled and operated by company. Even Some out of controlled processes.
Secondary Data	Average data	Average data
Proxy data	Not accepted	Accepted
Others	Not mentioned	Recommended
Data age	At least 1 year	Not clear

Validity of analysis	Two years	Not clear just mentioned that until a significant change occur in the process boundary
Verification process	Three types Self declaration Accredited third party Non accredited third party	Two types Self declaration Accredited third party
Reporting and Communication requirements	Not mentioned	Mentioned in very detailed

5.11 Comparative applicability of PAS2050 and the GHG protocol initiative for CF of concrete

The usefulness of the two standards or methodologies (PAS and GHG protocol) for this project is discussed in this section based on the product characteristics identified in section 5.4. The pros and cons of these two methodologies are evaluated for the identification of best possible option out of these two for calculating CF of concrete in relation to the objective of the study.

- **Concrete mixes composition changes relative to end use and customer demand**

The GHG protocol initiative describes very detailed about the allocation of GHG when recycled or waste of some other process is used in different ratios for different quality products of same category. It refers De-facto to closed loop recycling in such cases. Whereas, PAS refersthe ISO standards for recycling except closed loop recycling.

- **One of the input materials has large environmental impacts compared to others**

If one of the resource materials contribute more than 50% in the total GHG emissions connected to the life cycle of a product then at least 95% of the emissions from the remaining sources must be calculated (PAS2050, 2008). There is no such guideline in the GHG protocol initiative.

- **Use of waste of some others processes as input material instead of virgin one**

The GHG protocol initiative describes this problem more detailed compared to the PAS2050.

- **Different end use phases**

The concrete product is used for different end use products (roads, bridges, buildings etc.) with different properties. To handle such situations is very difficult and there is no satisfactory explanation in both methods.

- **Long life of end use product**

According to the PAS2050 CO_2 uptake from the atmosphere, by any nonliving product over a 100 year period of assessment the impact of this CO_2 storage shall be included in the life cycle GHG assessment of the product.

- **Recyclable product**

The concrete material is recyclable but not fully so to calculate the savings of GHG on recycling after long life is very difficult. In most cases the concrete waste from concrete buildings at end of their life is used as base material for roads and new buildings which alternatively save emissions over virgin material. None of the two methods give information on this matter.

- **The intent of CF study**

The intent of this CF study is to communicate CF information both internal and B2B. The PAS is suitable both for B2B and B2C communication. Whereas, the GHG protocol initiative is originallyintended from corporate perspective.

From the above discussion it is hard to chose which one is the best, generally speaking. However, the PAS2050 is selected for the calculation of carbon footprint of concrete. The chosen methodology is accepted based on the following three main reasons.

i. PAS2050 is more compatible for concrete carbon footprint. This is retrieved from the above comparison of different methodologies.
ii. The data requirements of this methodology are more close to the state of availability of data in the company.
iii. The PAS2050 is more convenient to use for the CF of a single a single product as compare to the Greenhouse gas protocol initiative.

As discussed above, in some situations GHG protocol is more elaborative as compare to PAS 2050. For example, in case of open loop recycling GHG protocol give more detailed guide lines while PAS refer PCRs. So in such situations the GHG protocol will also be consulted.

6 Carbon Footprint of Ready Mixed Concrete

6.1 Carbon FootprintObjectives of TCG AB

The TCGconsiders its activities' environmental impacts on local and global environment. According to the CEO of TCG work with environment is necessary for long term profitable and competitive business. The group has strong ambitions in playing a significant role in developing a sustainable society globally by local actions (TCG, 2011).

The reasoning behind this study is strong concern of group to climate conditions, the stakeholders whose emissions inventory depend on the product (RMC) they buy and its applications. The development of a CF tool to assist company´s stakeholders in accounting and comparing the GHGs connected to their choice of concrete recipe.

The followings are the overall objects of the company for having its product carbon footprint.

- To monitor and reduce GHGs emissions.
- To communicate the products carbon footprint to the costumers if requested
- To benchmark carbon footprint of concrete within the group and with competitors.
- Incorporate emissions impact in decision making about suppliers, materials, product recipes selection and formation etc.
- Demonstrate environmental/ corporate responsibility
- Meet customers' demands on carbon footprint.

The company consider that all of the above reasons are important. The CF of concrete will help both the company itself and its potential customers, especially the building construction companies, in appropriate choice of recipe when they have a plan to construct buildings for environmental certifications such as LEED and BREEAM as described in sections 3.2 and 3.3.

6.2 Goal and Scope

In this chapter the goal and scope of this carbon footprint (CF) study are elaborated in more detail. The scope part includes discussion on CF calculation methodology, system boundary and finally limitations.

Goal definition

The goal of this study is to calculate GHGs or CF connected to the concrete produced at Färdig Betong AB Ringögatan 14, Göteborg. This CF of RMCwould be helpful for decision making and to integrate the product supply chain in order to locate the possibilities of reduction in environmental burden.

The concrete plant has more than 200 concrete mixture recipes with different maximum coarse aggregate size, varying amount of coarse aggregate quantity, amount of cementitious materials, admixtures etcetera. To enable specific carbon footprints to be calculated the most frequently used recipes have been divided into 5 main types[19] based on similar properties and very small differences. The resulting database will be used to develop CF tool to facilitate the user to easily calculate the carbon footprint of a specific concrete type.

6.2.1 Scope and modelling requirements

The following part of the study states how much of the concrete life cycle will be included in the calculation of CF considering the goal definition.

Functional Unit

The functional unit (f.u.) to be used for this CF study is one cubic meter (m^3) of concrete produced at Färdig Betong. The unit has been chosen based on the fact the concrete produced at the company is in semi liquid form not a solid one and the calculation of CF is based on the cradle-to-gate LCA. It means that LCI is to the gate of the construction site and before setting of the concrete.

Type of LCA

This LCA is an accounting type because the goal is to collect GHGs emissions data throughout the processes mentioned in the process flow chart. This meets the first objective directly mentioned in section 6.1 whereas the others will likely be achieved indirectly.

Choice of impact categories and method of impact assessment

Carbon footprint/global warming potential due to GHGs emissions will only be calculated. In addition, other environmental impacts categories such as toxicity, acidification, eutrophication and land use are not considered because of limited time and data. The PAS 2050 method will be followed to calculate GHGs emissions.

Technical scope

A very brief flow chart of process under study is shown in figure 4. The raw materials extraction mean the acquisition of natural resource like sand and gravel and their processing mean the extractionand crushing of rock to required aggregate size, washing to remove any clay and/or inorganic impurities etc.

The company purchases cement and admixtures directly from the respective producers. The GHGs connected to the production ofcement and admixtures will be taken from the life cycle (cradle-to-gate) inventory of the respective companies. The GHGs emissions from the transport of cement and admixtures and others to

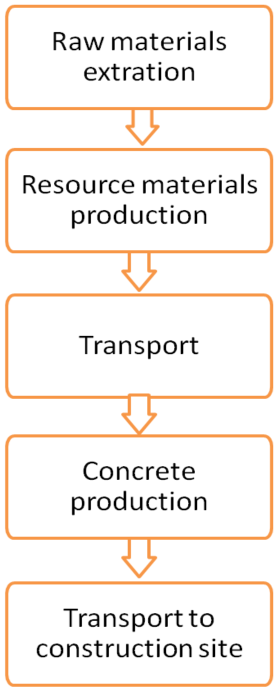


Figure 4: Initial Flow Chart of Concrete Production

[19]***SC***: Standard Concrete (Strength class), ***CMR***$_{w/c}$:Concrete with Maximum water to cement (w/c) ratio (for exposure conditions according to EN206-1 & SS 137003). ***CMA***$_{w/c}$: Concrete with maximum water to cement ratio and minimum air content (Air for concrete expansion to freezing and thawing). ***F&T***: concrete tested for freeze-thaw conditions. ***SCC***: Self compact Concrete

and from the concrete production plant will be calculated based on the PAS2050 guide lines. Emissions related to the business trips and direct and indirect land use are excluded.

The concrete production is the main process that is directly under the control of Commissioner Company and includes several sub process that could have large impacts on GHGs inventory of concrete production because of large amount of energy (electricity) use.

System Boundaries

System boundaries are positioned based on the PCRs EPD type-III (PCR, 2005) as PAS 2050 demands. Wherever, it is not possible to fulfil the PAS requirements, elaboration is provided.

Geographical boundary: For this, PAS refer PCRs if exist for a similar product system. In this case most of the processes in the system boundary are practiced in Sweden, so according to the PAS system boundary, Sweden is established. Moreover, this LCA study is specific to Färdig Betong Ringögatan 14, Goteborg plant. However, it might be used for others TCG´s production plants in Sweden and other countries with changes in transport distances figures because almost all TCG plants have similar production technology.

Temporal boundary: It is very hard to exactly find the time when raw materials for cement and admixtures are extracted, processed and used. Therefore, according to the PAS2050, 100 years time perspective is used for this study. It means that all the GHGs emissions connected to the product supply chain are occurring within 100 years time.

According to the PAS2050 results of this study will be valid for two years and in case of any significant change within the system boundary processes validity could be expire before two years.

Greenhouse gases: According to the PAS2050, 2008 all the GHGs listed in IPCC2007 climate change reports shall be included. In this case study due to lake of data and time only CO_2, CH4 and N_2O are considered as GHGs. All included GHGs will be measured and reported as CO_2-eq. The GWP on these GHGs will also be presented on CO_2-eq basis and calculated over 100 year’s time perspective in accordance to PAS2050.

Emissions from the capital goods are excluded but from the energy used in operations of premises such as emissions from operation plant facilities and offices etc are included. The emissions from electricity produced by wind, hydro and bio-fuel energy resources are assumed neutral. For hydro, wind and bio-fuels electricity, no geographical boundaries are drawn.

Storage facilities: Both raw materials and product do not require special storage facilities. Hence, no additional emissionshere.

Limitations and assumptions

The transports to and from the plant are included but the transport of aggregates and waste materials within the plant boundary are excluded due to lack of information.

The emissions from the water production process are omitted due to minute value and lack of exact amount of water used at production site. The production of consumable things such as printing paper and ink are left out due to time constraint and miner impacts. The energy and materials used at concrete testing laboratory are omitted due to time limitations.

The average values of electricity and oil used for processes within the plant boundary and for all types of concrete over the whole year are taken for carbon footprint calculation. No separate information is available even though there is much difference in values for different types of concrete and over different seasons (winter and summer).

The site specific data is used for all the resources production processes except chemical admixtures.

6.3 Inventory Analysis

The intent of this section is to describe individual process from data source, assumptions and calculation method´s point of view. This is done to facilitate the reader and illustratethe reliability of data used.

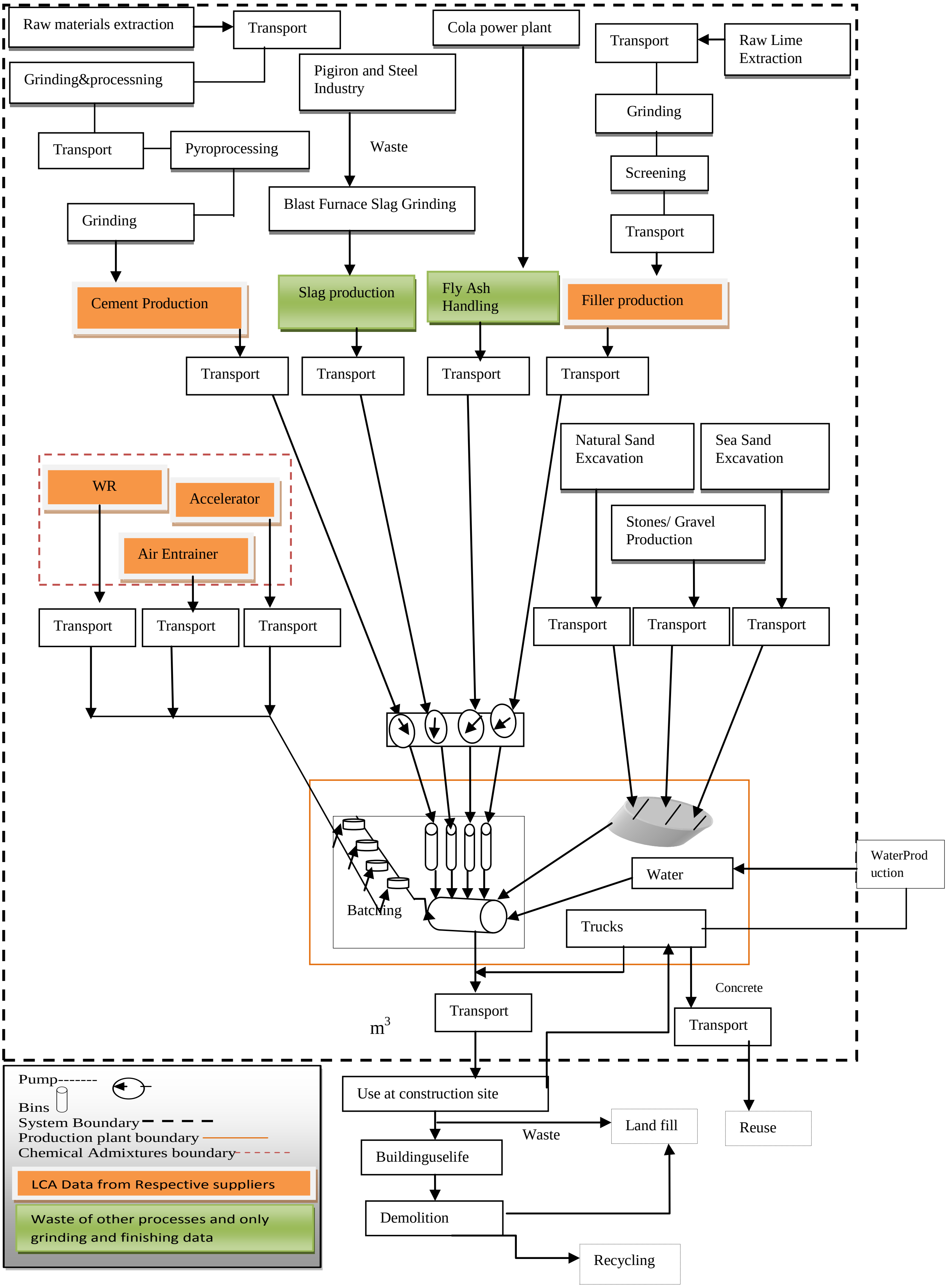
A detailed flow chart of full life cycle of concrete is shown in figure 5 below. The flow chart is sketched after a thorough visit of the RMC production plant and consultation with the persons in company. It is divided into three parts Upstream (background processes), Main stream (operations under direct control of company) and Downstream processes. The data for most of the upstream processes is collected from the respective suppliers and for processes controlled by the company is site specific.

Almost all processes have inputs such as electricity and fuels and outputs like product, emissions and waste are included in the studied system although not displayed in the flow chart.

All the calculations done here are according to the production of concrete at Färdig Betong, Ringöngata 14, Göteborg. According to IngemarLöfgren[20] the production processes is fairly similar at all TCG plants. Hence, the inventory results could also be followed for other plants with some changes in transport modes and distances.

[20] Personal communication: Manager Thomas Concrete Group - C.labRingön 14 Göteborg (2011-04-11).

Figure5: Ready Mixed Concrete Production Life Cycle Inventory Flow Chart



Cement Production

The TCG, Färdig Betong Ringögatan14, purchases cement (CEM I) from CEMENTA Degerhamnand CEM II/A-LL from CEMENTA Skövde. Due to unavailability of latest site specific data on energy consumption and emissions, CEMENTA Degerhamn,Skövde sustainability report is used for values on emissions from cement production. According to the report life cycle inventory the GHG emissions are given in table 12. These values are used for the calculation of CF of concrete.

Table 12: Emissions per ton of cement production

GHGs	CEM I	CEM II	Unit	Reference
CO_2	839	726	Kg/ton	(CEMENTA, 2008)
CH_4	0,000	0,000	Kg/ton	
N_2O	0,00	0,00	Kg/ton	

Slag production

Slag is not currently used at Ringön but is being introduced. The slag comes from Holcim (Germany) to Ringögatan14. The amount of energy used during processing, grinding to ready to use in concrete production is taken directly from the company. The electricity and coal used in slag production are presented in Table 13.

Table 13: Energy consumption per ton of Slag production

Resource	Energy Type	Value	Unit	Reference
GGBS (Slag)	Electricity	67.06	Kwh/ton	(Holcim, 2011)[21]
	Coal	6.25	Kg/ton	

The emissions from the electricity used are calculated according to the sources of electricity production in Germany (IEA, 2008). Whereas, the emissions from coal combustion are calculated according to the emission factors given in LCA in a nutshell (Tillman,et.al., 2004).

Fly Ash production / Handling

The fly ash is described in chp.2 of this report.The production process of fly ash is almost zero CO_2 emission. Even its use in cement and concrete avoid many other environmental problems such as transport to land fill and leaching of metals (Hick, 2009) but here just avoided emission due to cement replacement is considered. Hence, only emissions from the transportation of fly ash are included.

[21]Direct contact to the company (Holcim; Germany) and data received on 18-04-2011.

Filler production

The lime stone powder (limus40) is used as filler in concrete production. It comes from the Nordkalk AB Sweden. Electricity and diesel oil is used in the production and the figures are presented in Table 14, due to confidentiality reasons oil used is not mentioned here.

Table 14: Electricity used in the production of lime

Energy	Value	Unit	Reference
Electricity Swedish mix (IEA, 2008)	42.6	Kwh/ton	(Nordkalk, 2011)
Diesel oil	Value omitted	Litre/ton	

Chemical Admixtures Productions

The chemical admixtures that TCG companies uses in concrete production are purchased from Sika group. To get site specific data contact was made to SikaSverige AB and the data provided was secondary data from the publications of European Federation of Concrete Admixtures (EFCA). This data is based on cradle to gate LCA and authorized to be used in LCA of Concrete studies (EFCA, 2002).

Superplasticizers

The Superplasticizers are used in dosage 1-4l/m^3 of concrete. The GHG emission data given in Table 15is applicable for all types of super plasticizers described in chapter 2.

Table 15: Eco-profile for 1 kg super plasticizers, 30-45% Active Content (EFCA doc 325 ETG, April 2006)

Emissions to Air	Unit	values
CO_2	g/kg	690
CH_4	g/kg	1.2
N_2O	g/kg	0.067

Air entrainer

Air entrainers are used from 0.2-0.3% by weight of cementand vary depending on requirements of air volume in RMC. The following data, provided in Table 14, is valid for air entrainer produced based on anionic and non-anionic synthetic surphactants, alkyleither, sulphates, sulphonic Acid and Abiatic acid.

Table 16: Eco-profile for 1 kg air entrainer, 3-14% solid content (EFCA doc.301ETG, January 2006)

Emissions to Air	Unit	values
CO_2	g/kg	860
N_2O	g/kg	0.0086
CH_4	g/kg	0.62

Accelerators

These are mixed to accelerate the setting time of RMC. The following data, presented in Table 17, is valid for accelerators based on the blends of Calcium and sodium salts of nitrate.

Table 17: Eco-profile for 1 kg accelerators, 35-50% solids(EFCA doc.300 ETG, 2006)

Emissions to Air	Unit	values
CO_2	g/kg	1200
NO_x	g/kg	2.3
CH_4	g/kg	2.5

Transportation of resources

There are several transport processes in the supply chain of the TCG product and these can also be seen in the life cycle flow chart of RMC figure 6. The study includes all types of resources transport from the production sites to the concrete batching plant and ready mix concrete to the customer's construction site.

According to the PAS2050 the calculated emissions from transport processes include both emissions from the fuel production and from the direct combustion of fuel. Two types of transport modes are used in this study, Road and Sea. The emission factors used to include the emissions from the production of fuels include emissions from the extraction of crude oil, refining and ready for use. The transport of fuel to the customers is not included. The GHG are calculated according to the Network for Transport and Environment´s (NTM) calculation methods (NTM, 2010).

In road transportation by trucks, NTM´s calculation method for road transport (NTM, 2010a) is adopted. The vehicles used in transportation of resources to and from the company are compared to the vehicles used by the NTM methods (50% load factors) based on the load transported.In table 18 the transport of resources to and products from the company, vehicles types and modes of transport and NTM calculation methods used are given.

Table 18: Resources transport modes, NTM vehicle types and GHG calculation methods

Resource	Mode of Transport	NTM´s Vehicle type	NTM´s method
CEM I, fly ash and slag	By Sea	RoRo 3000 lane meter (Max cargo load, 6320 ton and load factor 88%)	NTM, 2010
CEM I &II, fly ash and slag	By Road	Tractor+ mega trailer (Max cargo load, 33 ton and load factor used 50%)	NTM, 2010
Filler (Lime stone powder)	Road	Tractor+ mega trailer (Max cargo load, 33 ton and load factor used 50%)	NTM, 2010
Gravel(sand) natural(0-8mm)	Sea and then Road	For sea RoRo 3000 lane meter (Max cargo load, 6320 ton and load factor 88%) and for road, Truck + semi trailer (Max cargo load 40 ton and used capacity 50%)	NTM, 2010

Stones 5-25 (Crushed)	Road	Truck + semi trailer (Max cargo load 40 ton and used capacity 50%)	NTM 2010
Chemical Admixtures	Road	Heavy truck (Max cargo load 15 ton and 50%capacity used)	NTM, 2010

In all road transport processes emissions from positioning distances are added to the total transport emissions. According to the NTM road transport methods 50% of the total distance is used as positioning distance because no information was available on positioning distances.

For all sort of transport diesel oil is used as energy carrier with well to wheel energy conversion factor 43MJ/litre and 2.9 Kg CO_2-eq/litre (NTM, 2010).

Processes under direct control of the company

Concrete batching process

The electricity is used for weighing of resources and missingof concrete at the batching plant. According to the PAS 2050 the electricity used by the provisioning functions such as lighting, heating, cooling, and plant control room equipments etc. is also added in this process. The value of electricity used in 2010 is presented in Table 19; the electricity used in 2010 is high (18.76 Kwh/m^3) due to a much cool winter as compared to some of the previous years. In 2007 it was 9.14 Kwh/m^3, in 2008 it was 9.5 Kwh and in 2009 it was 17.43 Kwh/m^3 (2009 was also a cool winter). These electricity values include the electricity used at concrete batching plant, plant management offices, lab and garage. The emissions are calculated according to the Swedish electricity mix production system.

Table 19: Electricity used at concrete batching plant

Process	Electricity used	Unit	Reference
Concrete Batching/production	18.76	Kwh/m^3	Annike Andreasson[22]

Water and aggregates heating

The municipal water is used in concrete batching process. For concrete production during winter, the water is first heated to approximately 80°C and diesel oil is used for heating. The amount of oil used for heating of water and aggregates per cubic meter of concrete is given in table 20.

Table 20: Diesel oil used in water boiler for water heating and also for aggregate

Process	Oil used	Unit	Oil heating value	Reference
Water + aggregates heating	0.86	Litre/m^3	43 MJ/l	Company data base

[22]*AnnikeAndreasson; Environmental manager TCG, Personal communication[21-04-2011]*

Concrete transport to the customers

The Ringön plant most often delivers concrete to construction sites within the radius of 10-25 km. Hence, on average 15km is used as concrete delivered trip and for this purpose concrete trucks are used. Due to absence of emission data and uncertainty in oil used per trip or km, NTM Road transport method is used for emissions calculation (NTM, 2010).

Truck washing

The concrete left in the trucks are washed out at the washing unit. The aggregate particles are separated at a first step by the separator. The water containing fine particles then passes several times a cyclone mounted with filters in order to separate the fine particle from the water. After this process almost clean water is flushed out into the municipal sewage system.

The waste material is not sent to land fill instead it is taken by someone who has use of it. The company does not know how long this waste is usually transported except that is used as base material for some sort of road construction.

For GHG emissions calculations it is assumed that this material is transported up to 10 km by the same trucks used in aggregates transportation. No positioning is included in this process.

Solid wastes

The solid waste at a concrete batching plant can come from;

- Concrete return to the plant from the construction site in concrete trucks
- Washing of the concrete mixing drum

In the first case amount of waste depending on the degree of washing that varies operation to operation. According to the production manager at Ringön, approximately 1% of concrete on average by volume is left over and washed out. According to this figure Ringön produced approximately 440 m^3 of concrete waste in 2010.

The waste from the washing of mixing drum is assumed to be included in the 1% value. This waste is also handled in the same way as in first case.

District heating

Until the end of 2010 heating system connected to offices, lab, garage and batching plantwas oil based. But now in 2011 the lab, offices and garage heating system is based on the combined heat and electric pumps. The oil and electricity used for this purpose in 2010 is included in water and aggregate heating oil values.

6.4 Inventory Results

In this setion the carbon footprint results over the life cycle of 1 cubic meter (1 m^3) concrete produced are presented on average 28 days compressive strengths by Concrete strength class, types and by individual sources (Figure 5, 6). The values on which the following graphs are drawn are used as database in carbon footprint tool and are also presented in Appendix III- Inventory Tables.

6.4.1 Scenario I: Normal Concrete

The normal concrete means concrete produced based on cement (CEM I or CEM II/A-LL) as binder. None of the other types of binders (e.g. fly ash) are added. The carbon footprint is presented in Figure 5, were the Cxx/yy is presenting Concrete strength class based on 28 daysstrength of cylinder(x) and cube(y) specimens.

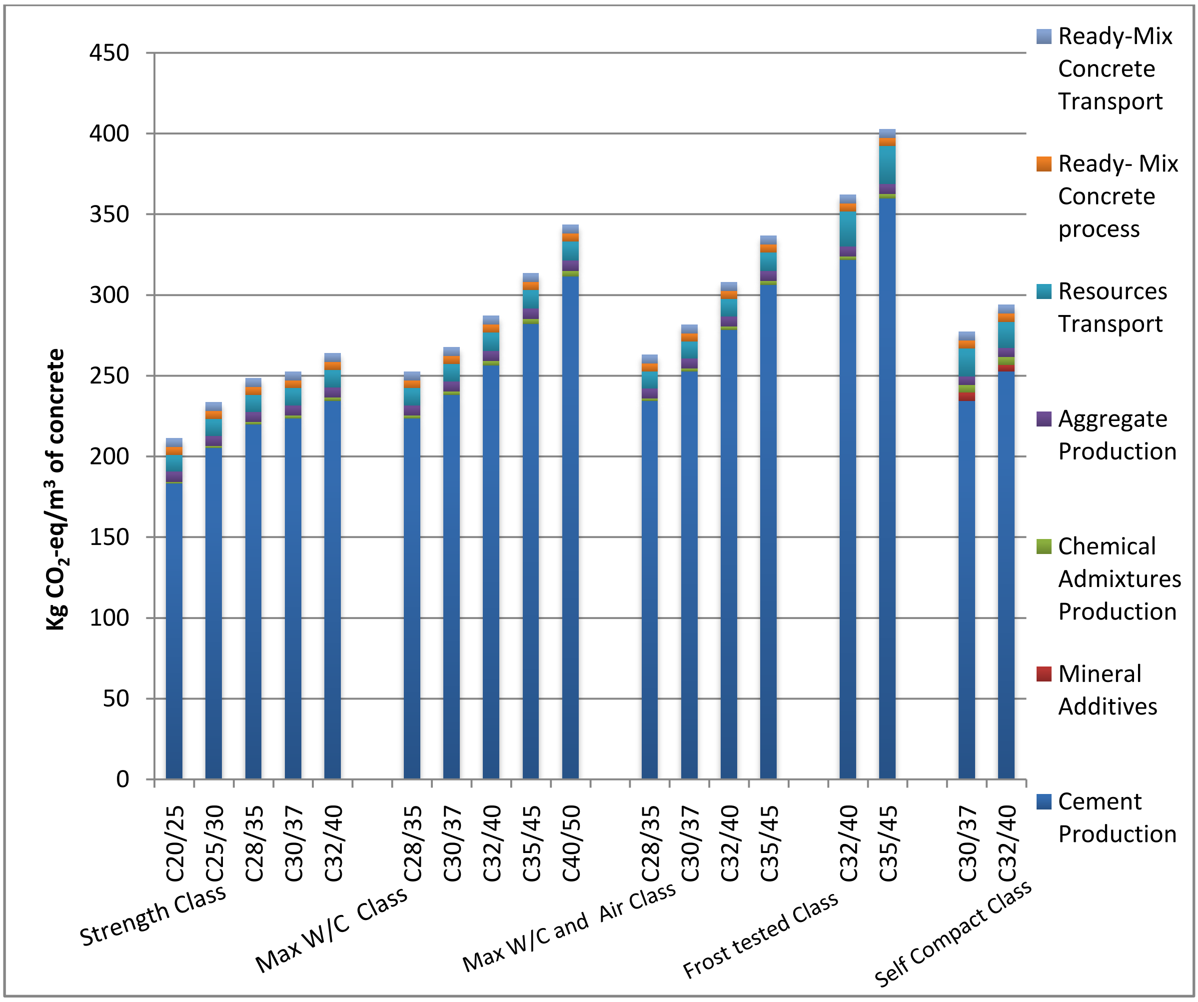
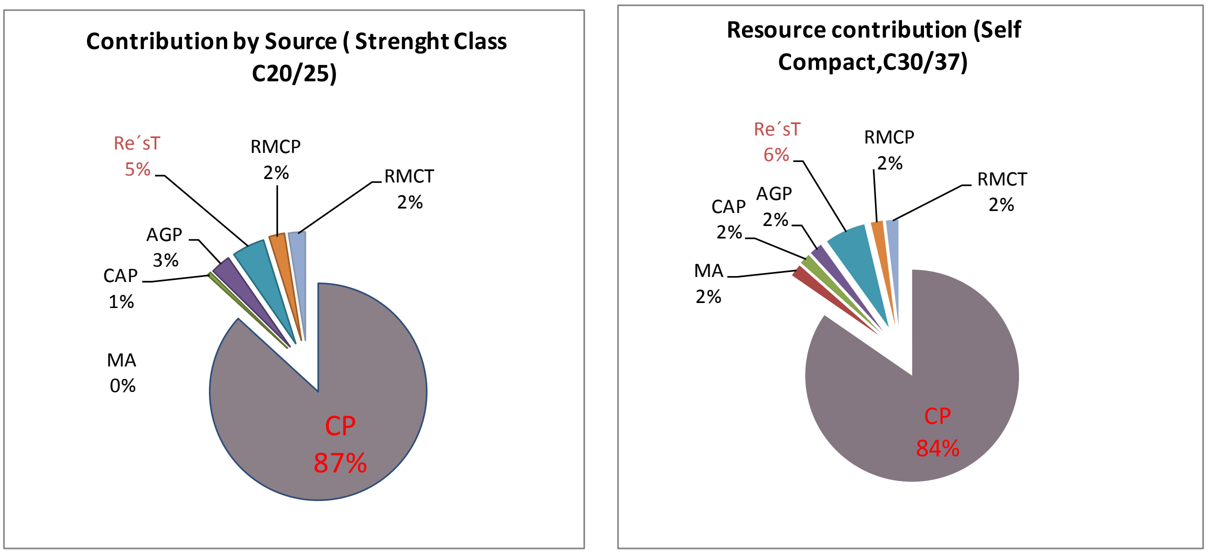


Figure 5: Contribution by sources to total CF of concrete in normal concrete with cement only as binding material.

Figure 6: Individual source contribution in percentage (%) to the total CF of RMC.



6.4.2 Scenario II: 100% distance travelled as positioning distance

In this case it is assumed that all vehicles used for road transport go empty back to the position. This is done to check the sensitivity of transport to the overall CF of concrete. The impact can be seen in Figure 7.

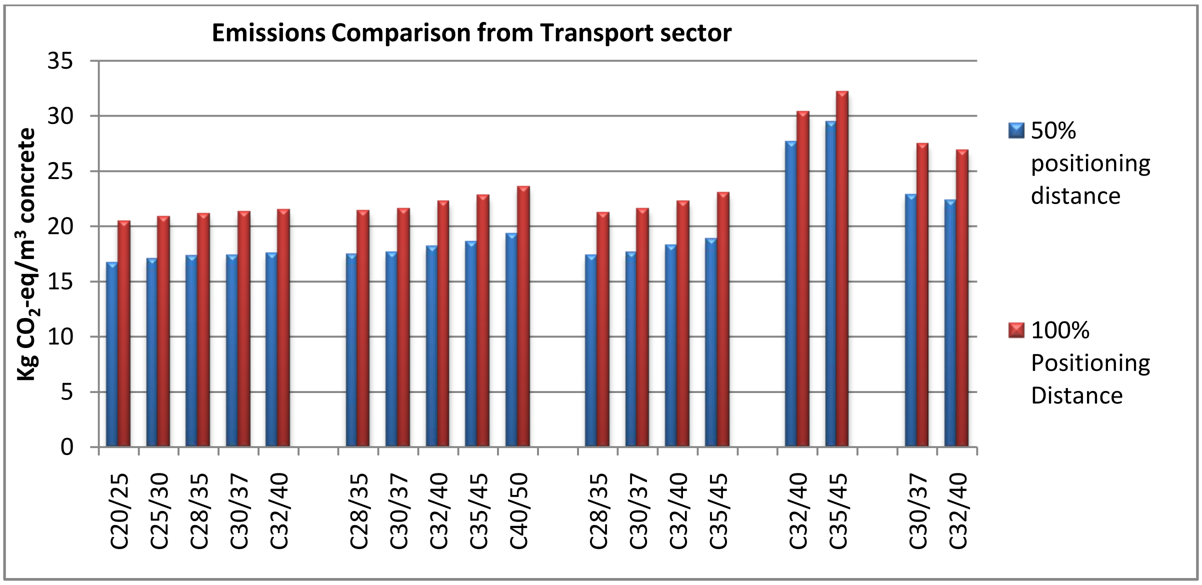


Figure 7: Difference in CO_2-eq emissions only from transport operations under two different satuations for road transport.

After cement production transportation is the second largest contributor to CF of concrete. It contributes approximately 8-10% to the total CF of concrete. However, it depends on transport mode and distance covered. With 100% as positioning distance the change in CF of concrete per cubic meter is roughly 5 kg as shown in Figure 7 above.

6.4.3 Scenario III: Concrete with Fly Ash (FA) Content

In this situation the cement is replaced with fly ash by 10%, 20%, and 40% on weight basis of the cement content.Whereas, according to the BREEAM rating scheme calculation methodology 10%, 20% and 40% FA contents are equal to 9%, 17% and 30% respectively.These are typically used dosages (higher dosages are sometimes used depending on application and exposure conditions but, limited also due to limiting values in SS137033 where dosages correspond to "xx/yy" ratio). The 10% FA content meets the LEED demand and 40% FA, BREEAM. The results from the carbon footprint calculation are presented in Figure 8.

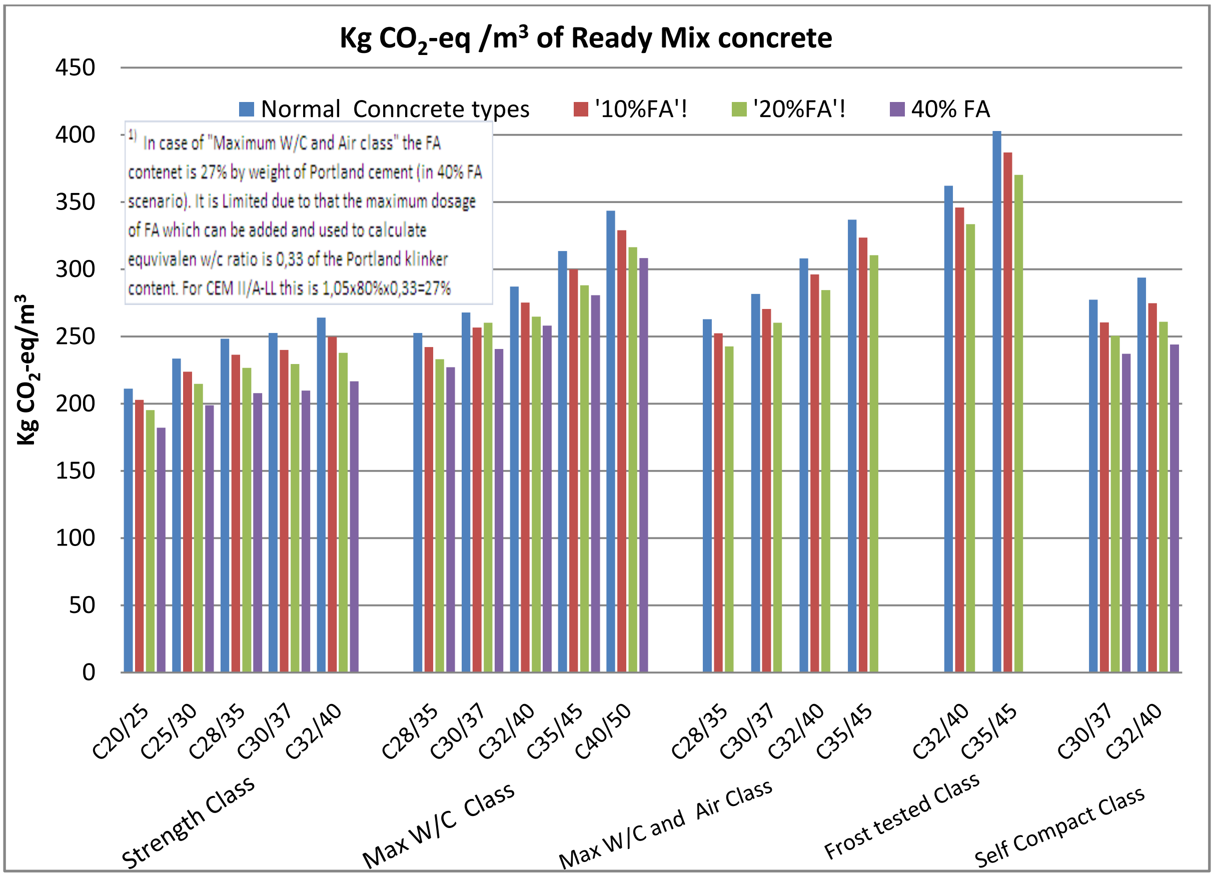


Figure 8:The CF of Ready Mix Concrete with 10%, 20% and 40% fly ash by weight of Portland cement as compared to Normal Concrete.

From the above Figure 8it is clear that the use of supplementary cementitious materials in concrete production have a big impact on CF of concrete. Using 20% fly ash by weight of cement can on average reducedthe CF of concrete by 10-15% and with 40% FA it ranged 13-17%.

6.4.4 Scenario IV: Concrete with GGBS (or Slag) Content

Figure 9 shows the relative decrease in CF of concrete with increasing content of supplementary cementitiousmaterial (SCM) GGBS by weight of cement. The use of post industrial materials up to 20% and 100% in ready mix concrete are the requirements of LEED and BREEAM respectively. The use of 25% GGBS (on weight of cement) is best possible option for all types of concrete and building projects which corresponds to 20% (on weight of total binders) according to BREEAM. However, for residential/commercial building a high dosage can be used as the exposure conditions for most of the structure is not that severe.The blending of GGBS at higher ratio is much better from environment side but it is not allowed in all exposure classes according to the Swedish concrete application standard SS 137003. However, at high dosages the early strength, particularly when cold, could also be a problem in all classes. For high content of SCM, concrete with only strength requirement or some of the classes with maximum w/c-ratio is more favourable.

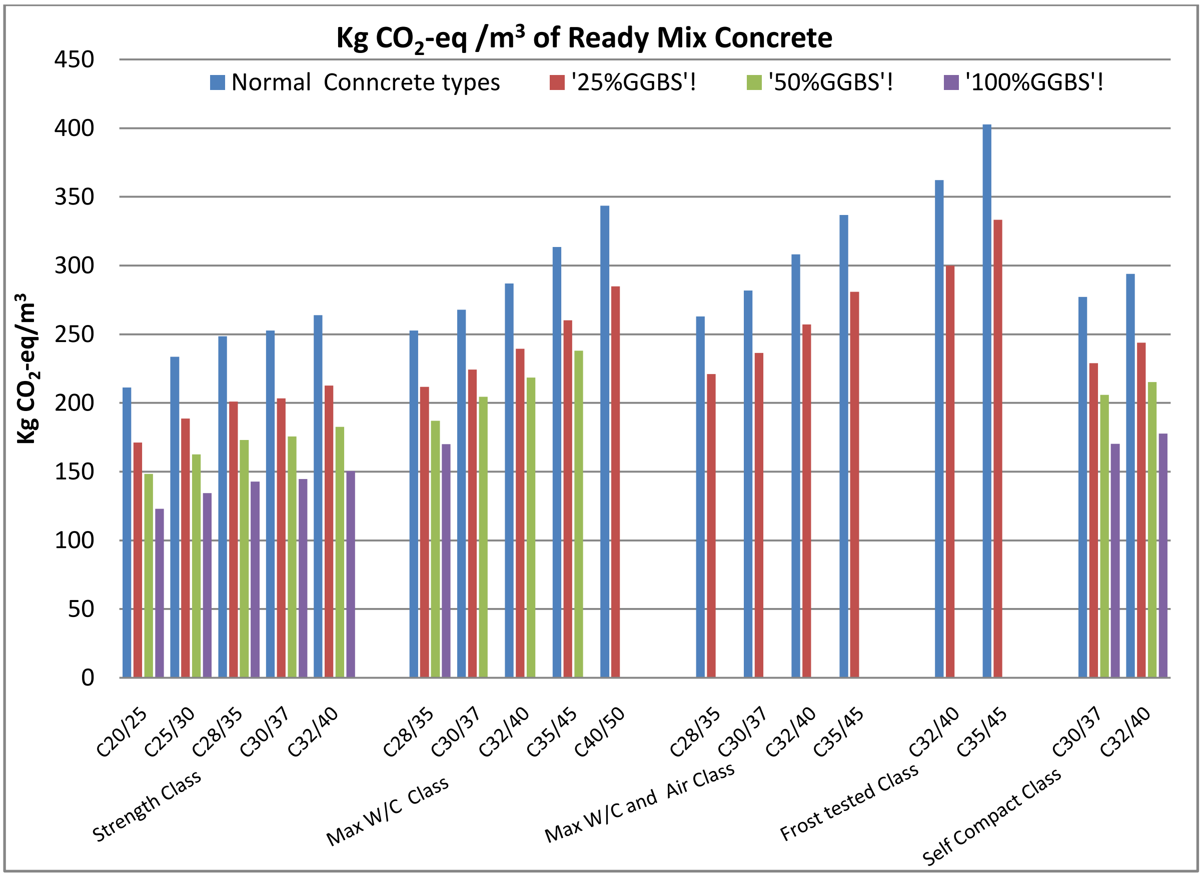


Figure 9:The CF of Ready Mix Concrete over three different levels of GGBS compare to Normal Concrete types.

6.4.5 Discussions on the Results

A single category GWP of environmental impacts is presented here. The results are based on the LCA (cradle to gate) and PAS2050 method is followed which is described in detail in previous Chp.4 and 5.

The above results indicate that the production of ready mix concrete itself is not a climate issue but the use of Portland cement as binder is the main contributing factor. The Portland cement contributes approximately 70 to 90% to the total CF of concrete depending on concrete type and dosage of supplementary cementitious materials. After cement the transport operations contribute 3 to 7% to the overall CF; however,it is largely dependenson the mode of transport and distances covered.

The further discussion is done under two different scenarios where cement is replaced by other cementitious materials likefly ash and slag/ GGBS, and this is also presented in Figure 10.

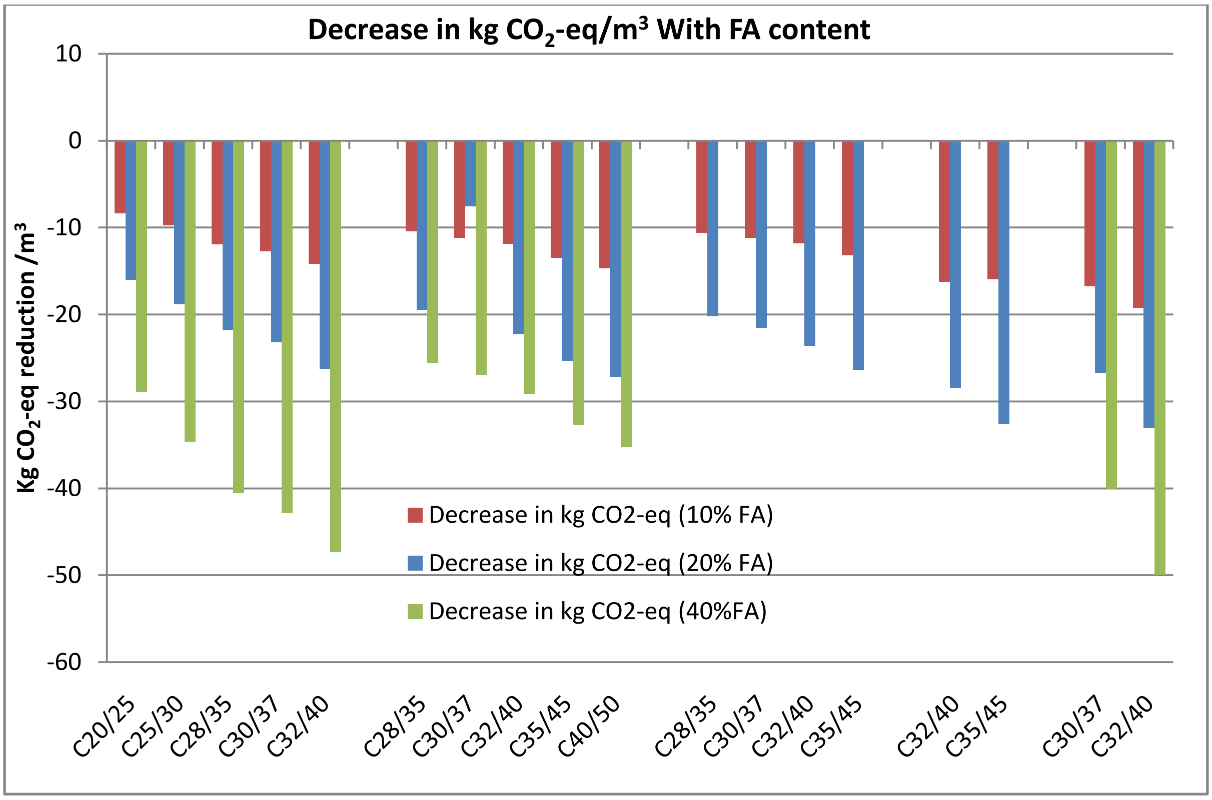


Figure 10: Decrease in CF of concrete by using FA as mineral additive compare to Normal concrete types (Scenario I).

Figure 10 indicates that by using 10% FA by weight of cement a 5% CF reduction can be achieved and the reduction is10% at 20% FA and 17% at 40% FA content.

In case of the GGBS the situation is even better,albeit the drying and grinding of GGBS require energy. Figure 11show that the use of slag is more beneficial as compare to FA because it can replace a large content of cement. By using 50% slag by weight of cementup to 22% CF reduction can be achieved (or 75 Kg CO_2-eq). Whereas, in case of equal amounts of cement and slag or GGBS the reduction is about40% (120 Kg CO_2-eq).

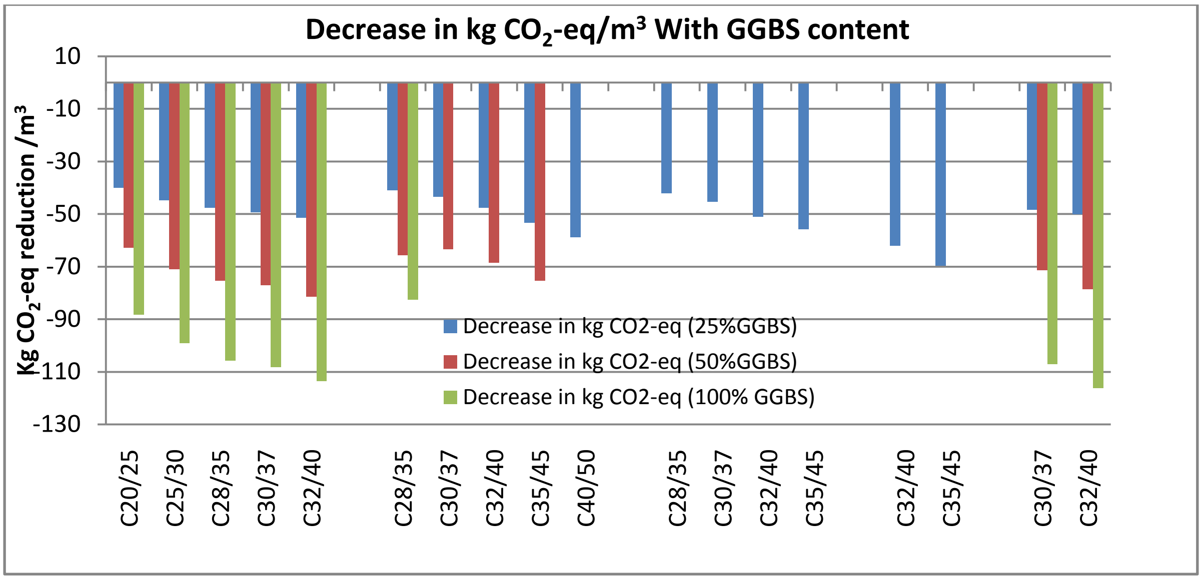


Figure 11: Influence on CF of concrete over three different content levels of slag compare to Scenario I.

The above results are valid within the system boundary described in chap.6 of this report.

The above discussion is very short and narrow to the use of alternative cementitious materials. Besidesit, there could be many other ways to reduce the CF of concrete. The other options are described in Chapter 10. However, for more detail information about the results see Appendix IV: Inventory Results.

7 Carbon Footprint (CF) Tool

7.1 Introduction

One of the objects of this project was to develop a simple CF tool for internal use in the company. The tool is developed in Microsoft Office (MS) excel 2007. It has one sheet with user guide, one as interface and one with outputs or results. The inputs or interface sheet is connected to the calculations made for individual processes of concrete production.In the same excel workbook, two sheets have concrete lifecycle calculation processes that are linked to the inputs sheet (know as user interface) to change the data and show results on the output sheet. The rest of the sheets have information about emissions factors and data sources.

7.2 CF Tool objectives

The intended use of TCG´s CF tool is to calculate the CF of a specific concrete produced at any one of the TCG´s plants. The tool will generate one value of CF per cubic meter of any concrete type. It will reported CF both in data values and graphical format by sources and in total on the same worksheet. It will also be possible to see what percentage comes from which source (e.g. cement production, resources transport etc.).

One of the important functions of this tool will be to use it for benchmark before taking any decision about changes in resource suppliers, transport mode and concrete batching technology etc. Itcan also be used to look at changes in CF on use of post industrial and post consumer materials in accordance to LEED, BREEAM or any such other ECS. The other objects that are also linked to this tool are described in chapter 6.

7.3 The “TCG´s Carbon Footprint Tool”

The complexity of a tool depends on how complexthe reference product is and the frequency of variations in that product(s) input ingredients. The developed CF tool is intended to have as few input parameters as possible, but still cover the essential, to motive users to use it frequently. The intended users of this tool will be the environmental and technical managers of TCG and Färdig Betong,in the end it may also be used by production managers as well.

The tool is so simple which just required concrete recipe values and transport distances of resources to the plant and transport of ready mix concrete to production site as shown in figure 12.

As soon as the required inputs are completed on “Inputs” work sheet the results will automatically be generated on the next sheet named as “Results or Outputs”.

7.4 The "Inputs" work sheet (user interface)

The Inputs work sheet is used as user interface here which is a very simple excel sheet with some information on concrete ingredients and transport modes used for this CF study. The interface can also be seen in figure 12.

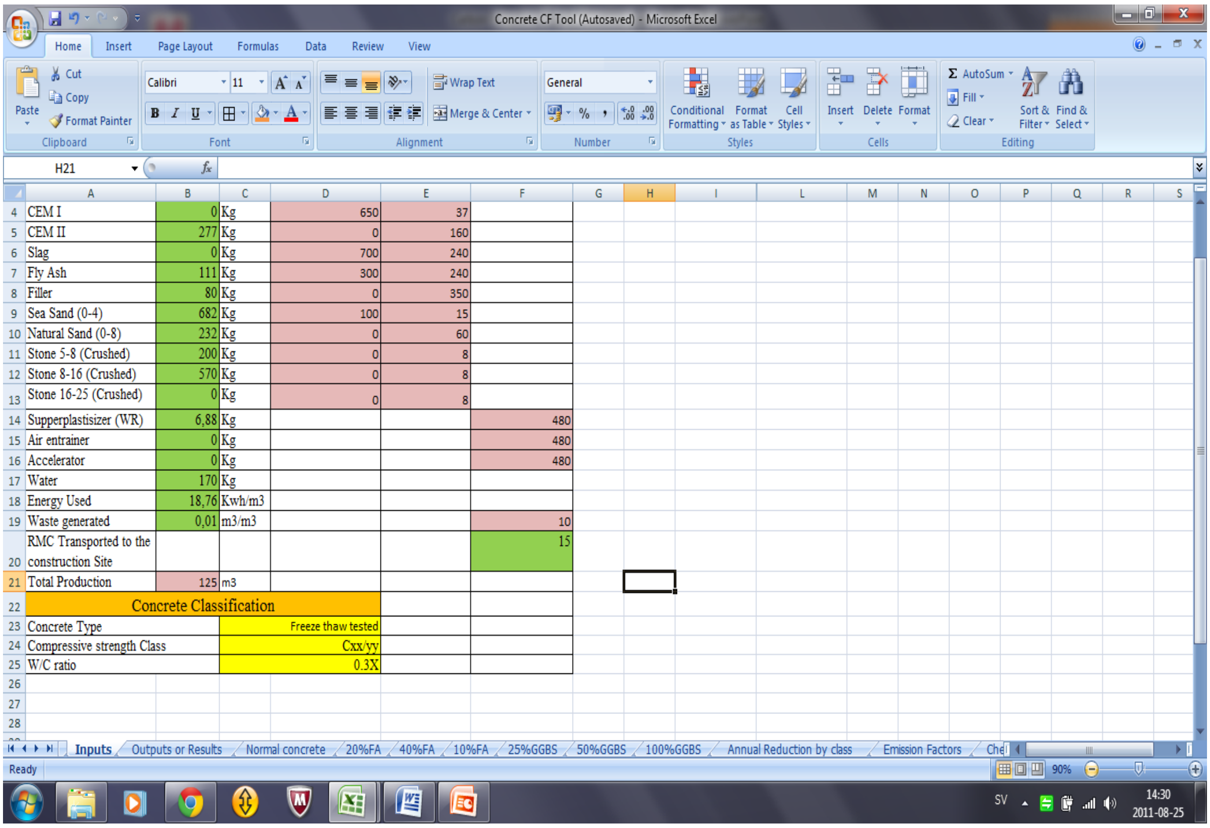


Figure 12: The Inputs or user interface of the developed CF tool

The interface is divided into three parts: (1) concrete recipe values (light green cells), (2) concrete classification (yellow cells) and (3) transportation distances (light red cells) which are differentiated with different colors. The green cells are for concrete resource materials proportions that are usually developed based on concrete strength requirements. The yellow color cells are about the concrete classification just to make the output results clear to the viewer even though this part has no effect on results. It requires concrete type, strength class (Cxx/yy) and water to cement ratio (w/c). These names will also be appeared on the output charts and in tables.

Almost all types of resource materials (e.g. CEM I, slag, FA, filler etc.) that are in use and can possibly be used in concrete production so far are fixed in this tool except fibres.

Secondly the values of resources transport distances in the light red cells would be required at least first time for each plant and for green cells values will have to be change with each change in product delivery. The transport modes are fixed in this tool and in case of any change in transport mode, changes in the database processes will be required.

7.5 The “Out puts or Results” work sheet

As soon as the user completes required fields in Inputs sheet, the inputs data will automaticallygenerate the calculated vales which then are presented on out puts or Results work sheet. The layout of results is shown in figure 13.

TCG´Carbon Footprint Tool (Outputs)

Concrete Type	Strenght Class	Ratio (W/C)	Unit	Cement Production	Mineral Additives	Chemical Admixtures Production	Aggregate Production	Resources Transport	Concrete Batching	Ready-Mix Concrete Transport	Kg CF & NOx of concrete
				CP	MA	CAM	AP	Re´sT	CB	RMCT	Total
Freeze thaw tested	Cxx/yy	0.3X	Kg CO2-eq/m3	203,1	2,3	5,1	5,4	17,8	5,0	5,2	244,0
			Kg NOx/m3	0,0755	0,0000	0,0125	0,0000	0,1795	0,0041	0,0344	0,3061
			Tons CO2-eq / total production	25,39	0,29	0,64	0,68	2,22	0,63	0,65	30,50
			Kg Nox / total production	9,44	0,00	1,56	0,00	22,44	0,52	4,30	38,26

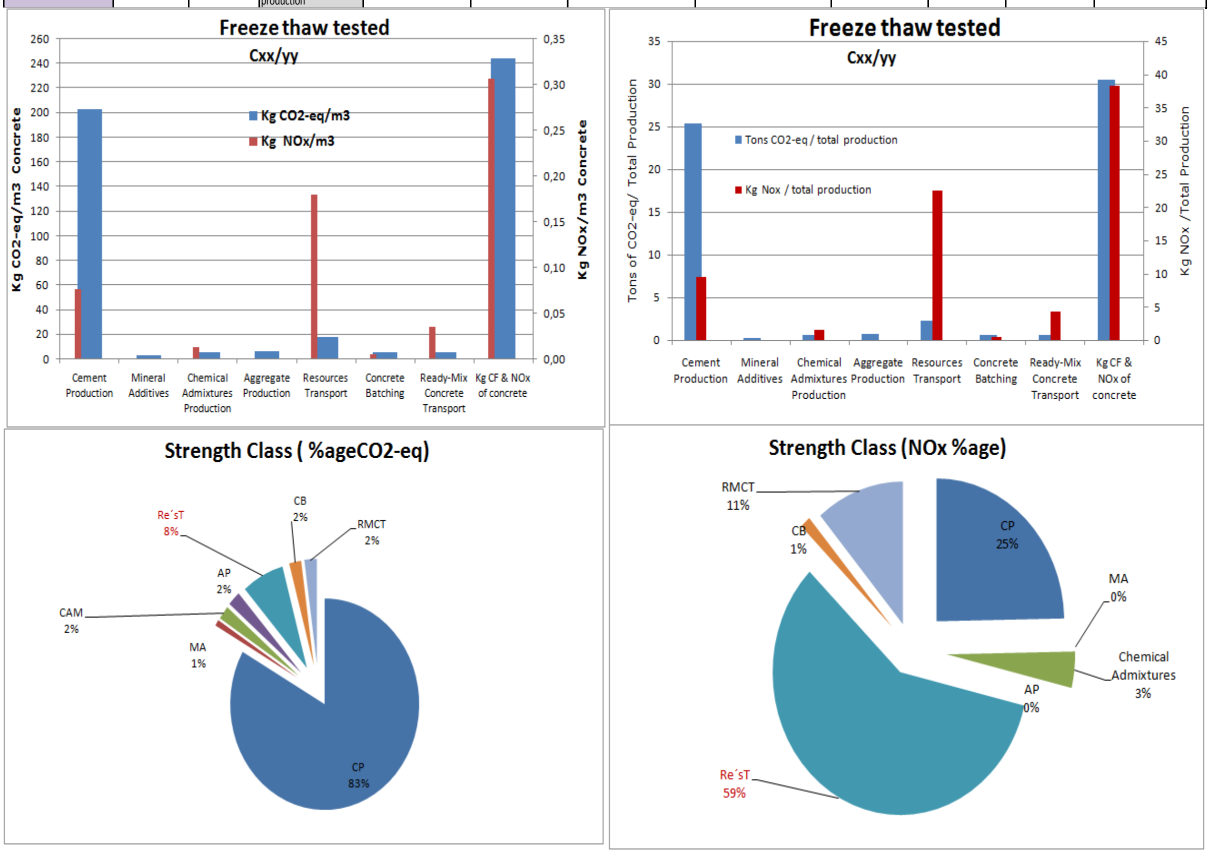


Figure 13: The CF and NOx, as it is generated when required inputs are fixed in Inputs sheet

The above result´s figure is showing information on CF and NO_x both in values and percentage by source and per cubic meter of concrete. Although the NO_x emissions calculation was not in scope of this study but it is included here because of the company demand. The right side bar chart is presenting CF and NO_x emissions over total amount of concrete produced of the same strength class. The inputs and generated results will remain until new inputs are given or removed.

7.6 Limitations

The tool is just for GWP and NO_x emissions from concrete production within the system boundary stated in chapter 4 of this report. The included GHG for CF calculation are CO_2,

CH_4 and N_2O. It is limited to use for a single type of concrete at a time. The total CF or NO_x over total production can only be calculated for a specific type of concrete recipe at a time not over total production of mix types.

8 Discussion

In this chapter conclusions from this study project are extracted and discussed under few headings and finally some suggestions are made for future studies related to this work.

8.1 Environmental Classification Systems, Stakeholder´s Response and CF of Concrete

Different ECS were studied and discussed within the project organizing team. Two of them LEED and BREEAM were decided for study in detail. As described earlier, TCG produces RMC and has much of its business with building construction companies such as NCC and SKANSKA. The purposes of this study was to understand what these systems say about concrete, what sort of demands construction companies can put on concrete producers in future,and what the group's main stakeholders say about the future applications of these systems.

The carbon footprint was a focal point of this study but several others parameters were also selected to gain a good understanding on the role of ECS in connection to the RMC environmental performance. Interviews were conducted from the selected stakeholders and analysed in reference to the following parameters.

- Number of ECS
- Role of LEED and BREEAM towards sustainable construction
- Role of RMC for higher rating
- The future role of these and such other ECS

Due to limited time not all important stakeholders could be interviewed but a selected number were interviewed. The questions that were asked can be seen in appendix 1. The imprecalresults of the interviews are given in the figure 14. It is just a rough figure and there is no such consistency in the results as shown in the following curve. About 85% of the

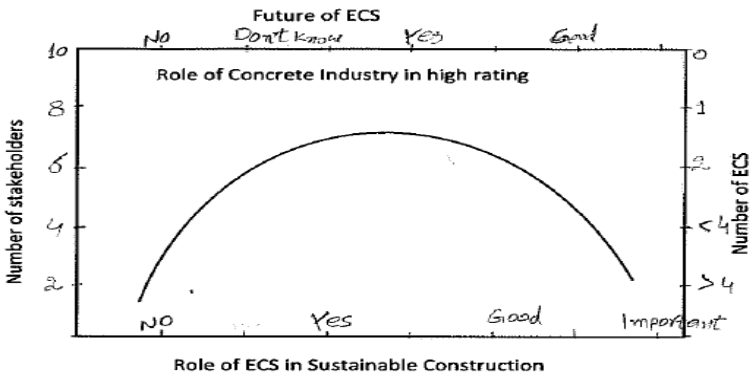


Figure 14: Analysis of stakeholders views based on four different parameters

stakeholders said that these systems have future and to achieve higher rating concrete producers should focus on light weight materials, low content of Portland cementand concrete with optimum content of post industrial and post consumer materials. In second parameter "Sustainable construction" a specific question on CF of concrete was asked to almost all. Some of them said it is good to have CF of building in rating systems on LCA basis but other environmental impacts should also be incorporated in such systems.

Furthermore, it is concluded that by working in a team through the engagement of professional experts of different disciplines (project manager, designers, architectures, concrete producers and environmental analysts etc.) at the initial phase of a project much better results (higher rating) can be achieved.

8.2 Concrete and the choice of CF methodology

To follow a standard methodology is almost a fundamental requirement of any type of CF study. A methodology not only facilitate the choices need for CF calculations but also important to increase the reliability of the results. For this CF study PAS2050 has been chosen as CF methodology.

Why it was selected? There were many reasons that have been mentioned in last section of the chapter 5 *Carbon Footprint Methodologies*. The two most important, that are discussed here, were connection to the BREEAM and future study benefits when including use phase processes.

First, as LEED and BREEAM are the most relevant ECS that have been studied and discussed in detail. From their study and specifically through the stakeholders' interviews it was realized that the BREEAM has higher applicability in the EU as compare to LEED. The BREEAM and PAS2050 are both developed in the U.K and is the most accepted standards in the EU countries. Hence, it was assumed that to follow the PAS2050 would be more appropriate,even though the results would probably be almost similar if any other method, such as international EPD would have been used instead.

Secondly, PAS2050 considers the carbon stored in non living products. Kenji, et al. (2005) in the article "The CO_2 balance of concrete in a life cycle perspective" and Nilsson & Fridh (2010) described that RMC absorbs CO_2 from the atmosphere and converts it into carbonates. The absorbed CO_2 can then be considered according to the PAS2050 if full life cycle assessment (cradle-to-grave) is done.

However, in case of allocation on recycling content PAS2050 does not provide any specific guidelines. In such cases EPD is more elaborative and could be the best option if concrete industry uses recycled aggregates in future.

8.3 Comparison with previous concrete LCA studies

When the results of this study were compared to the studies done by Marceau, et al. (2007) and Sjunnesson (2005), the GWP of this study is somewhat lower in several cases. In comparison between ordinary concrete (C20/25) produced at TCG and also studied by Sjunnesson (2005), the CO_2-eq/m^{3}of RMC is13% lower (or 35kg CO_2-eq/m^3) due to lower cement content (approximately 40kg/m^3) and transport distances and in comparison with Marceau, et al. (2007) the values are similar. However, when concrete with requirement on max w/c ratio and strength class C32/40 was compared with the same one studied by Marceau, et al. (2007) the CO_2-eq/m^3 of RMC is 7% lower (or 23 kgCO_2-eq/m^3) because of lower cement content (approximately 5kg/m^3). The comparison can be done because the system boundaries of the compared studies are approximately similar.

8.4 Will this study make any difference?

According to the TCG environmental manger, C.Lab manager and business developer this study will make a change in the production of concrete as whole. A few customers have started to ask for CF information and through the use of the CF tool the company will not only be able to meet this demand but will also show the difference in CF for different types of concrete to its customers.

The results of this study show that the concrete batching process itself is not contributing a significant amount to the CF of concrete as compared to the resource production. The cement production and resources transport operations are the main contributorsto the CF in the life cycle of RMC.

The transport of RMC through heavy trucks and cement by truck trailer over long distances are the major contributors of CF within the transport operations. The cement production has the largest CF within the production of resource materials. In normal concrete (scenario I) Portland cement production contributes 85-90% to the total CF of RMC production. The higher CF of freeze-thaw tested concrete is due to higher content and the use of a pure Portland cement (CEM I).

The Scenarios III and IV that are developed according to the LEED and BREEAM requirements on post industrial materials content show a big difference in CF of RMC compare to Scenario I. It is concluded that the replacement of Portland cement with SCM (e.g. slag and fly ash) can reduce the CF of RMC from 5-10% with 10-20% FA and 17-40% with 25-100% slag. Apart from this, there could be many other means to reduce the CF (e.g. transport operations, heating of water and aggregates etc.) where a little effort can give a positive outcome.

8.5 Field experiences

Information on data needed about resource materials was asked to the current suppliers most of them replied. Some referred to their environmental reports (sometimes quite old)while others replied that they do not have complete information.

In the beginning suitable persons were identified. E-mails and telephone calls were made to get time for interview. Most of the selected replied and accepted the interview, while some either did not reply or referred to someone else.

At the end it was concluded that to approach a right person and to get complete right and fair information is the most difficult task. It was also found that everybody accepted the importance of the environmental issues but not all were ready to do and provide exact information required according to the LCA standards used in this study.

9 Conclusions and suggestions for future studies

9.1 Conclusions

Along with carbon footprint other environmental impacts should also be incorporated in rating systems on LCA basis to meet environmental challenges.

Almost all the external stakeholders said that increasing environmental information will introduce strict environmental regulations. The LEED and BREEAM and such other environmental classification systems will be more and more use in future. Hence, the concrete industry should ready to assist the construction companies to meet such demand. The concrete industry need to analyse its resource supply chain and focus on local, renewable energy and materials resources.

Based on the interviews, it has been concluded that through the engagement of professional experts of different disciplines (project manager, designers, architectures, concrete producers and environmental analysts etc.) at the initial phase of a project much better results (high rating level) can be achieved.

In case of allocation on recycling content PAS2050 does not provide any specific guidelines. In such cases EPD is more elaborative and could be the best option if concrete industry uses recycled aggregates in future.

The study results show that the replacement of Portland cement with SCM (e.g. slag and fly ash) can reduce the CF of RMC from 5-10% with 10-20% FA and 17-40% with 25-100% slag. Apart from this, there could be many other means to reduce the CF (e.g. transport operations, heating of water and aggregates etc.) where a little effort can give a positive outcome.

At the end it was concluded that to approach a right person and to get complete right and fair information is the most difficult task. It was also found that everybody accepted the importance of the environmental issues but not all were ready to do and provide exact information required according to the LCA standards used in this study.

9.2 Suggestions for future studies

At the first step, a third party should be asked for verification of the CF calculations of this study according to the PAS 2050 to improve the calculations and to get them certified. This act would be in benefits of the TCG AB because it will strengthen the reliability of the results and then the results could be used for business to business (B2B) communication.

A full LCA including other environmental impact categories (e.g. Eutrophication, and Acidification etc.) should be performed with maximum use of site specific data. This can then be used to increase the impact catageories result of the developed CF tool. It will not make any change in the interface of the tool because the same number of inputs will generate results including other impact categories. To make the tool more easy to use it could be developed by using some sort of web based application systems such as VBA, C, and C^{++} etc.

In this case the CF tool will just need concrete type (Cxx/yy) and the plant name; all the rest inputs it will take automatically from the concrete production database.

A full LCA under different scenarios of reuse, recycle and landfill of demolished concrete buildings should be analysed to illustrate a full sustainability potential of different types of concrete as compare to other types of structures (e.g. wood, steel etc.).

A further detailed study on hotspots identified in this study such as cement production and transport operations should be done to look at the options that need a bit work and where much saving could be achieved.

In some special cases such as import and use of SCM, switching some transport to bio-fuel or train, an implementation of cost benefit analysis (CBA) could be the best option to identify financial benefits as well.

There is a need to identify other companies that are working or having policy to work with the LEED or BREEAM to ask them how concrete can assist them in attaining higher level rating. The questions should be broadened,not just limited to CF, to identify other possible options where concrete industry can do work and have financial and environmental benefits. This action can bring two sided benefits to the TCG. One can be a possibility to have business with other companies and the other can help in lowering the internal environmental burden.

10 References

Abdulrahman, M. A.lhozaimy, Riyadh, MohdSalehJaafar,R. M. S., Al-Negheimish Riyadh, Serdang (MY), JamalodinNoorzaie,J.(2011): Concrete Aggregate Composition, Concrete product and methods for mixing a concrete product. Pub.NPub. NoO. US2011/0048287 Ab, March, 3, 2011.

Ashley, E. and Lemay, L. 2008: The Journal of Green Building Volume 3, Number 4 fall 2008 by College Publishing.12309 Lynwood Drive, Glen Allen, VA 230J;9 (USA).

Ashley, E. and Lemay, L. (2008, P. 39): "Concrete´s Contribution to Sustainable Development" Journal of Green Building, volume 3 number 4,Print ISSN: 1552-6100 | Electronic ISSN: 1943-4618

Azar, C. (2008): Makten över klimatet. Falun: Albert Bonniersförlag.

BASTA (2011): accessed at http://www.bastaonline.se/ownload/18.7df4c4e812d2da6a416800014004/BASTA+Properties+Criteria+2011_2.pdf [checked out, 16 Feb. 2011 at 10am]

Baumann, H. and Tillmann, A. M. (2004, p.23): The hitch hiker´s guid to LCA. An orientation in life cycle assessment methodology and application.

Baumann, H. and Tillmann, A. M. (2004, Table Appendix 1.10): The hitch hiker´s guid to LCA. An orientation in life cycle assessment methodology and application.

Bolin, B. (2008): A History of the Science and Politics of Climate Change – The Role of the Intergovernmental Panel on Climate Change. New York: Cambridge university press.

BREEAM (2009): BREEAM Europe Commercial 2009 Assessor Manual, SD 5066A: ISSUE 1.1. Published by the BRE, UK.

BREEAM (2011): found at www.breeam.org: visited, 21 Feb 2011 at 15:00

British Cement Association (1999): "Concrete through the Ages – from 7000 BC to AD 2000"

BRMCA (2009): The Guidance Document on'Sustainable Concrete Design and Rating Systems' published in September 2008 by the British Ready Mixed Concrete Association (BRMCA), Ref. BRMCA/01/09.

Brook, O. (2003, p.4): A Report on the "Green Building Movement" a journal of White Paper on Sustainability published by Building Design and Construction , Underwritten in part by:INDUSTRYDuro-Last Roofing, Inc. Interface Flooring Systems/Bentley Prince Street and The Vinyl Institute Lafarge North America, Federal Agencies: U.S. General Services Administration and United States Department of Energy

CAA (2006) b: Cement Admixtures Association: Admixture Technical Sheet – ATS 2 super plasticising/High range water reducing, can be accessed at http://www.admixtures.org.uk/ [accessed.19 April 2011]

CAA (2006)a: Cement Admixtures Association: Admixture Sheet – ATS 5, Concrete Air-entraining admixtures, can be assessed at http://www.admixtures.org.uk/ [accessed.19 April 2011]

CAA: (2006)c: Cement Admixtures Association : Admixture Sheet – ATS 4, accelerating admixtures, can be assessed at http://www.admixtures.org.uk/ [accessed.19 April 2011]

Carbon trust (2011):Available at http://www.carbontrust.co.uk/cut-carbon-reduce-costs/calculate/ carbon-footprinting/pages/carbon-footprinting.aspx [Accessed: 28 March 2011 at 13:00pm]

CEMENTA (2008, 2009, p.4) : Utsikt Bilaga till Heidelberg Cement NorthernEurope'shållbarhetsredovisning 2008-2009, temanummer. The report can be downloaded from the CEMENTA website www.cementa.se

CEMEX: News from the company communication department at December 7, 2010. http://www.cemex.com/MediaCenter/PressReleases/PressRelease20101207.aspx

Den Elzen, M. G. J. Detef P., Van Vuuren,V.P.D., Paul L. Lucas, L.P., Bas eickhout, Bart, J., Strongers, J.B., Bas Van Ruijven.V.B., Wonink, S., Roy VanS., Houdt,R.V.(2006, p.143-149): an Article of Climatic Change (2007) 81:119–159, DOI 10.1007/s10584-006-9172-9 “Stabilizing greenhouse gas concentrations at low levels, an assessment of reduction strategies and costs”.

ECCO (2003): Environmental Council of Concrete Organizations: A case study journal “LEED Green Building Rating System Classification system and Concrete” published by the Environmental Council of Concrete Organizations in 2003.

EFCA (2006): EuropeanFederation of Concrete AdmixtureAssociations doc. 325 ETG Environmental Declaration Superplasticising Admixtures

EFCA(2006), doc.300 ETG: Environmental Declaration Air Entraining Admixtures December

EFCA (2006), doc.300ETG:Environmental Declaration Accelerating Admixtures– December 2005.

Elcock, D. (2007): Life Cycle thinking for the oil and gas exploration and production industry, Environmental science division, Argonne National laboratory (ANL/EVS/R-07/5) Chicago,US.pp.14-15. found at http://www.ead.anl.gov/pub/doc/LCA_final_report.pdf [Accessed 24 March 2011]

Environmental History Timeline: Information is found at http://www.radford.edu/~wkovarik/envhist/10eighties.html [checked out 12 Feb 2011 at 10:30am]

ERMCO (2009): European Ready Mixed Concrete industry statistics year 2009 published by the European Ready Mixed Concrete Organization.

European Concrete Platform (2009): Report Title "Sustainable Benefits of Concrete Structures" published by the European Concrete Platform ASBL in 2009.

Fardigbetong (2011): found at http://www.fardigbetong.se/precast-concrete/about.asp [Accessed: 5 Feb. 2011]

Hick,J.K., Riley, P.E. M., Schumacher,G., Patel, R., and Sampson, P., (2009): Utilization of Recovered Materials for High Quality Cements and Products.

Holcim, (2011): A German salg producing company, direct contact to the company and data was received at 2011-04-18, http://www.holcim.de/index.php?id=5840

IBEC (2011): Fond at http://www.ibec.or.jp/CASBEE/english/certified_bldgs.htm, visited, 18Feb 2011 at 12:45.

IEA (2008): Data on electricity production by source is collected according to the IEA 2008 that can be seen at http://www.iea.org/stats/electricitydata.asp?COUNTRY_CODE=SE

IEA (2008): The electricity production by source (e.g. coal, gas, wind, solar etc.) are accounted according to the IEA energy statistics at this site. http://www.iea.org/stats/electricitydata.asp?COUNTRY_CODE=DE[assessed 6 Jun 2011]

IPCC (2007a, p.17): Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland.

IPCC (2007b): Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 26, Chapter 1.

Ispra (2009):Found athttp://www.eu-greenbuilding.org/fileadmin/ Greenbuilding /gb_redaktion/guidelines/GBP_Guidelines_v2-2s.pdf [January 2011].

Jónsson, G. (2005): Icelandic Building Research Institute; CO2 uptake during the concrete life cycle:Information on the use of concrete in Denmark,Sweden, Norway and Iceland

Kawai, K., Sugiyama,T., Kobayashi, K. and Sano,S. (2005): “Inventory Data and Case studies for environmental performance, Evaluation of concrete structure construction” p. 1, Journal of Advance Concrete Technology, Vol. 3(2005) , No. 3 p.435-456, Japan Concrete Institute.

Kejin, W. (2004): Proceedings of the International Workshop on, Sustainable Development and Concrete Technology [Beijing, China, May 20–21, 2004]

Kjellsen, K.O., Guimaraes, M., and Nilsson, Å. (2005): “The CO2 Balance of Concrete in a Life Cycle Perspective” ISBN: 87-7756-758-7

LEED (2009): LEED 2009 for New Construction and Major Renovations Rating System issued by USGBC 2008, Washington, DC 20037. The PDF file can also be found at http://www.usgbc.org/ShowFile.aspx?DocumentID=5546)

Levinson, R. and Akbari, H. (2001, p.4): Effects of Composition and Exposure on the Solar Reflectance of Portland Cement Concrete, Lawrence Berkeley National Laboratory University of California Berkeley, CA 94720

Marceau, M. L., Nisbet, M. A., and VanGeem, M. G. (2007) : Life Cycle Inventory of Portland Cement Concrete published by the Portland Cement Association (USA), PCA R&D Serial No. 3011

Mindess, S. and Aitcin, P.C. (2011): Sustainability of Concrete (book: Morden Concrete Technology, p.17) published by the Spon Press. ISBN 13: 978-0-415-57196-8(hbk)

Mindess, S., Young, J. F., Darwin, D. (2002): Concrete; Second Edition. Chp.3, P.20

NCC (2011): http://www.ncc.se [accssessed 2011-5-12]

Nilsson, L-O. & Fridh, K. (2009 & 2010): CO2-cycle in cement and concrete Part 1: Examination of a previous NIC-project and Part 2: Further literature study on mechanisms/models. It is published by the Division of Building Materials the Lund Institute of Technology. ISRN LUTVDG/TVBM--09/7201--SE(1-17) and ISSN 0348-7911 TVBM

Nordkalk (2011): It is lime production company in Sweden and data was collected through direct communication to the company.http://www.nordkalk.se , Data received 2011-04-20

NRMCA (2009): “National Ready Mixed Concrete Association, Sustainability Initiatives” a report published by the NRMCA in 2009.

NTM (2010): All sort of GHG emissions from road and sea transport are calculated according to the calculation methods give at NTM website, http://www.ntmcalc.se [assessed 2011-04-14]

NTM (2010a): http://www.ntmcalc.se/Magellan/render/fuels [assessed 2011-04-14]

Pagliano, L., Dama, Alessandro: TheEuropean Green Building Programme, “Building Envelope Technical Module” vol. 3: End-use Efficiency Research Group (EERG) – Building Engineering Faculty - Politecnico di Milano.

RMCAO (2011): found at, www.rmcao.org: Concrete and Sustainable development (Visited, 12am, 19 January 2011).

RMC-LEED Guide reviewed (2005): LEED Reference Guide Third Edition 2005 published by The Ready Mixed Concrete Industry (RMC) Research & Education Foundation found at www.rmc-foundation.org

Sakai, E., Ishida, A. and Otha, A. (2006): New trends in the development of chemical admixtures in Japan. Journal of advance concrete technology, vol. 4, No. 2, p. 211-223, June 2006

Sakai, K. (2008): Sustainability in the concrete sector: CO2 reduction scenarios, Koji Sakai, Kagawa University, Takamatsu-Japan. A journal of Sustainability, published by the Concrete Engineering International

Sika (2005): A report “Sika Concrete Handbook” published by the Sika Services AG, Corporate ConstructionCH-8048 Zürich, Switzerland.

SIS (2011): Report on, Cement - Composition, specifications and cement with moderate heat (MH-cement) available at http://www.sis.se/byggnadsmaterial-och-byggnader/byggnadsmaterial/cement-gips-kalk-bruk/ss-1342022006 [accessed 2011-06-8]

Sjunnesson, J. (2005): A master thesis report, title “Life Cycle Assessment of Concrete” published by the Lund University department of Technology and Society, ISRN LUTFD2/TFEM--05/5009--SE + (1-61)

SKANSKA (2011): http://www.skanska.com [accssessed 2011-5-12]

Stern, N. (2007): Article of Economic and Climate change; Stern Review Report on the Economics of Climate Change, ISBN number: 0-521-70080-9. Chapter 7

TCC (2009): A report “Concrete and the Green Guide” published by the Concrete Centre, First published 2009, Ref: TCC/05/17, ISBN: 978-1-904818-79-3.

TCG (2011): http://www.tcg.nu/Company/tcg-ab.asp [Accessed: 5 Feb. 2011]

TCG : TCG:(2011):http://www.tcg.nu/Environmental/testsida.asp [searched out Tuesday 8 February 2011 at 11:16pm.]

UNFCCC (2009): Kyoto Protocol [online]. The United Nations Convention of Climate Change.Avaliable at: http://unfccc.int/kyoto_protocol/items/2830.php [Accessed: 21Feb 20011].

Veidikke (2011): http://en.veidekke.com [assessed 2011-05-20]

Vestergaard Nielsen, C. (2008): “Carbon Footprint of Concrete Buildings seen in the Life Cycle Perspective” a journal of Concrete Technology Forum Publishedby NRMCA in 2008

Wanielista, M. (2007): Performance Assessment of a Pervious Concrete Pavement Used as a Shoulder for an Interstate Rest Area Parking Lot. University of Central Florida, June 2007.

WBCSD (World Business Council for Sustainable Development), (June 2009, p.17): The Cement Sustainability Initiative issued by the WBCSD. Pub.No. ISBN: 978-3-940388-48-3. And the project director was Howard Klee, (klee@wbcsd.org).

Weidema, B. P., Thrane, M., Christensen, P., Schmidt, J. & Løkke, S. (2008): Carbon Footprint, A Catalyst for Life Cycle Assessment? Journal of IndustrialIndustrial Ecology journal, Volume 12, Issue 1, p. 3-6, Wiley-Blackwell.

White (2011): http://en.white.se [accessed 2011-05-27]

Wiedmann, J. & Minx, J. (2007): A definition of ‘Carbon Footprint’. ISAUK Research Report 07-01, UK Reseach& Consulting.

Wikipedia (10 June 2011): http://en.wikipedia.org/wiki/Global-warming_potential

Wikipedia (16 Feb, 2011):found at, http://en.wikipedia.org/wiki/U.S._Green_Building_Council visited 17 Feb 2011 at 9:00am

WSP (2010): WSP annual report and accounts 2010. Available at http://www.wspgroup.se/upload/documents/PDF/financial%20reports/Annual%20Report%202010.pdf and visited on 16 May 2011 at 10:00.

10.1 Appendix I. ECS (LEED) and Category credits

	LEED credits distribution	
Sustainable Sites		26 possible points
prerequisite 1	Construction Activity Pollution Prevention	Required
Credit 1	Site Selection	1
Credit 2	Development Density and Community Connectivity	5
Credit 3	Brownfield Redevelopment	1
Credit 4.1	Alternative Transportation—Public Transportation Access	6
Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Rooms	1
Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	3
Credit 4.4	Alternative Transportation—Parking Capacity	2
Credit 5.1	Site Development—Protect or Restore Habitat	1
Credit 5.2	Site Development—Maximize Open Space	1
Credit 6.1	Stormwater Design—Quantity Control	1
Credit 6.2	Stormwater Design—Quality Control	1
Credit 7.1	Heat Island Effect—Nonroof	1
Credit 7.2	Heat Island Effect—Roof	1
Credit 8	Light Pollution Reduction	1
Water Efficiency		10 Possible Points
Prerequisite 1	Water Use Reduction	Required
Credit 1	Water Efficient Landscaping	2 to 4
Credit 2	Innovative Wastewater Technologies	2
Credit 3	Water Use Reduction	2 to 4
Energy and Atmosphere		35 Possible Points
Prerequisite 1	Fundamental Commissioning of Building Energy Systems	Required
Prerequisite 2	Minimum Energy Performance	Required
Prerequisite 3	Fundamental Refrigerant Management	Required
Credit 1	Optimize Energy Performance	1 to 19
Credit 2	Onsite Renewable Energy	1 to 7
Credit 3	Enhanced Commissioning	2
Credit 4	Enhanced Refrigerant Management	2
Credit 5	Measurement and Verification	3
Credit 6	Green Power	2
Materials and Resources		14 Possible Points
Prerequisite 1	Storage and Collection of Recyclables	Required
Credit 1.1	Building Reuse—Maintain Existing Walls, Floors and Roof	1 to 3
Credit 1.2	Building Reuse—Maintain Existing Interior Nonstructural Elements	1
Credit 2	Construction Waste Management	1 to 2
Credit 3	Materials Reuse	1 to 2
Credit 4	Recycled Content	1 to 2
Credit 5	Regional Materials	1 to 2
Credit 6	Rapidly Renewable Materials	1

Credit 7	Certified Wood	1
Indoor Environmental Quality		15 Possible Points
Prerequisite 1	Minimum Indoor Air Quality Performance	Required
Prerequisite 2	Environmental Tobacco Smoke (ETS) Control	Required
Credit 1	Outdoor Air Delivery Monitoring	1
Credit 2	Increase Ventilation	1
Credit 3.1	Construction Indoor Air Quality Management Plan—During Construction	1
Credit 3.2	Construction Indoor Quality Management Plan—Before Occupancy	1
Credit 4.1	Low-Emitting Materials—Adhesives and Sealants	1
Credit 4.2	Low-Emitting Materials—Paints and Coatings	1
Credit 4.3	Low-Emitting Materials—Flooring Systems	1
Credit 4.4	Low-Emitting Materials—Composite Wood and Agrifiber Products	1
Credit 5	Indoor Chemical & Pollutant Source Control	1
Credit 6.1	Controllability of Systems—Lighting	1
Credit 6.2	Controllability of Systems—Thermal Comfort	1
Credit 7.1	Thermal Comfort—Design	1
Credit 7.2	Thermal Comfort—Verification	1
Credit 8.1	Daylight and Views—Daylight	1
Credit 8.2	Daylight and Views—Views	1
Innovation and Design Process		6 Possible Points
Credit 1	Innovation in Design	1 to 5
Credit 2	LEED Accredited Professional	1
Regional Priority		4 Possible Points
Credit1	Regional Priority	1 to 4
Total		110

10.2 Appendix II: The E-mail and example questions sent to the Stakeholders

Dear Mr. /Miss,

I am Master Student at Chalmers University of Technology, Goteborg,working with my Master of Science thesis. The thesis title is “The CarbonFootprint of Ready Mixed Concrete and Role of Environmental Classification systems such as LEED and BREEAM. The thesis is conducted in collaboration with the Thomas Concrete Group AB and Färdig Betong (under supervison ofIngemarLöfgren).

One part of the thesis is to collect information about the usefulnessand future role of the LEED and BREEAM from a practical point of viewthrough interviews of different stakeholders.

Your function as [insert function here] plays a key role in thepractical application of green building rating systems, LEED andBREEAM. Therefore, my study would greatly benefit from anunderstanding of your work and I kindly ask you for an interview.Following my project schedule a preferable time for interviews isbetween “April 15th to 30th 2011”. The interview will take about 30minutes.

Please reply with your preferred time(s) for this interview should youaccept. If you have any questions about this project don’t hesitate tocontact me.

Your co-operation is greatly appreciated and is vital to this work andthe outcome will have a good result.

Looking forward to your reply!

Best Regards,

Questions to be asked:

1. How familiar are you with LEED and BREEAM?
2. Do you think these systems are helpful in fulfilling the environmental obligations you have?
3. What do these systems not do for you?
4. What do you say about the future role of these systems?
5. Do you think that these systems are leading towards sustainable construction practice?
6. Regardless of these systems, what is your view on Sustainability, the Concrete Industry, and concrete as a construction material?
7. In terms of sustainability and sustainable construction, what other materials compete with concrete and how do you think that concrete compares?
8. In what way do you think/suggest that the ready mixed concrete industry can assist with sustainable construction and by achieving higher ratings in LEED and/or BREEAM?

9. Do you see some value of sustainable houses? And are people willing to pay little bit more for LEED or BREEAM certified buildings?

10.3 Appendix III: IPCC GHGs their life time and GWP coefficients

10.3.1 Table 21: IPCC GHGs their life time and GWP coefficients

Industrial Designation or Common Name	**Chemical Formula**	**Lifetime (years)**	**Radiative Efficiency (W m–2 ppb–1)**	**Global Warming Potential for Given Time Horizon**			
				SAR‡ (100-yr)	**20-yr**	**100-yr**	**500-yr**
Carbon dioxide	CO_2	See below *a*	*b* 1.4x10–5	1	1	1	1
Methane *c*	CH_4	12 *c*	3.7x10–4	21	72	25	7.6
Nitrous oxide	N_2O	114	3.03x10–3	310	289	298	153
Substances controlled by the Montreal Protocol							
CFC-11	CCl_3F	45	0.25	3,800	6,730	4,750	1,620
CFC-12	CCl_2F_2	100	0.32	8,100	11,000	10,900	5,200
CFC-13	$CClF_3$	640	0.25		10,800	14,400	16,400
CFC-113	CCl_2FCClF_2	85	0.3	4,800	6,540	6,130	2,700
CFC-114	$CClF_2CClF_2$	300	0.31		8,040	10,000	8,730
CFC-115	$CClF_2CF_3$	1,700	0.18		5,310	7,370	9,990

Halon-1301	$CBrF_3$	65	0.32	5,400	8,480	7,140	2,760
Halon-1211	$CBrClF_2$	16	0.3		4,750	1,890	575
Halon-2402	$CBrF_2CBrF_2$	20	0.33		3,680	1,640	503
Carbon tetrachloride	CCl_4	26	0.13	1,400	2,700	1,400	435
Methyl bromide	CH_3Br	0.7	0.01		17	5	1
Methyl chloroform	CH_3CCl_3	5	0.06		506	146	45
HCFC-22	$CHClF_2$	12	0.2	1,500	5,160	1,810	549
HCFC-123	$CHCl_2CF_3$	1.3	0.14	90	273	77	24
HCFC-124	$CHClFCF_3$	5.8	0.22	470	2,070	609	185
HCFC-141b	CH_3CCl_2F	9.3	0.14		2,250	725	220
HCFC-142b	$CH3CClF_2$	17.9	0.2	1,800	5,490	2,310	705
HCFC-225ca	$CHCl_2CF_2CF_3$	1.9	0.2		429	122	37
HCFC-225cb	$CHClFCF_2CClF_2$	5.8	0.32		2,030	595	181
Hydrofluorocarbons							
HFC-23	CHF_3	270	0.19	11,700	12,000	14,800	12,200

HFC-32	CH_2F_2	4.9	0.11	650	2,330	675	205
HFC-125	CHF_2CF_3	29	0.23	2,800	6,350	3,500	1,100
HFC-134a	CH_2FCF_3	14	0.16	1,300	3,830	1,430	435
HFC-143a	CH_3CF_3	52	0.13	3,800	5,890	4,470	1,590
HFC-152a	CH_3CHF_2	1.4	0.09	140	437	124	38
HFC-227ea	CF_3CHFCF_3	34.2	0.26	2,900	5,310	3,220	1,040
HFC-236fa	$CF_3CH_2CF_3$	240	0.28	6,300	8,100	9,810	7,660
HFC-245fa	$CHF_2CH_2CF_3$	7.6	0.28		3,380	1,030	314
HFC-365mfc	$CH_3CF_2CH_2CF_3$	8.6	0.21		2,520	794	241
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	15.9	0.4	1,300	4,140	1,640	500
Perfluorinated compounds							
Sulphur hexafluoride	SF_6	3,200	0.52	23,900	16,300	22,800	32,600
Nitrogen trifluoride	NF_3	740	0.21		12,300	17,200	20,700
PFC-14	CF_4	50,000	0.10	6,500	5,210	7,390	11,200
PFC-116	C_2F_6	10,000	0.26	9,200	8,630	12,200	18,200

PFC-218	C_3F_8	2,600	0.26	7,000	6,310	8,830	12,500
PFC-318	$c\text{-}C_4F_8$	3,200	0.32	8,700	7,310	10,300	14,700
PFC-3-1-10	C_4F_{10}	2,600	0.33	7,000	6,330	8,860	12,500
PFC-4-1-12	C_5F_{12}	4,100	0.41		6,510	9,160	13,300
PFC-5-1-14	C_6F_{14}	3,200	0.49	7,400	6,600	9,300	13,300
PFC-9-1-18	$C_{10}F_{18}$	>1,000 *d*	0.56		>5,500	>7,500	>9,500
trifluoromethylsulphurpentafluoride	SF_5CF_3	800	0.57		13,200	17,700	21,200

Notes: The above table of GHGs is adopted from" http://www.tropical-rainforest-animals.com/List-of-Greenhouse-Gases.html". This site refers that this list of greenhouse gases is an exact extract from the IPPC Report: *Working Group I: The Physical Science Basis of Climate Change. Technical Summary*, pp. 33 - 34. Retrieved from: http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_TS.pdf on June 17, 2008

10.4 Appendix IV- Inventory Results

Abbreviations*[23]

10.4.1 Table 22: Inventory results comparison over five different scenarios, average values for concrete types (Kg CO_2-eq/m³ RMC)

Concrete Types	Normal (No SCM)	10% FA	20% FA	25% Slag	50% Slag	100% Slag
	ARC	ARC	ARC	ARC	ARC	ARC
Strength Class	242.0	230.6	220.8	195.4	168.4	139.0
Maximum w/c ratio	292.9	280.6	272.6	244.1	212.0	170.1
Maximum w/c and Air	297.4	285.7	274.5	248.8		
Frost tested	382.4	366.4	351.9	316.6		
Self-Compacting Concrete	285.6	267.6	255.7	236.4	210.6	174.0

10.4.2 Table 23: Inventory results (Normal), average values for concrete types (Kg CO_2-eq/m³ RMC)

Concrete Types	Cement & Mineral Additives Production	Chemical Admixtures Production	Aggregate Production	Resources Transport	Concrete Batching	Ready-Mix Concrete Transport	Normal (No SCM)
	CP+MA	CAP	AGP	Re´sT	RMCP	RMCT	ARM
Strength Class	213.4	1.5	6.3	10.6	4.9	5.3	242.0
Maximum w/c ratio	262.5	2.6	6.3	11.3	4.9	5.3	292.9
Maximum w/c and Air	268.2	1.9	6.2	10.9	4.9	5.3	297.4
Frost tested	341.1	2.3	6.2	22.7	5.0	5.3	382.4
Self-Compacting Concrete	253	4.8	5.4	16.7	5.0	5.3	285.6

[23] w/c= Water to Cement ratio, SCM=SupplementaryCementitious Materials, FA=Fly Ash, ARC= Average Ready-mixed Concrete (mean average values of mixed design is followed),

10.4.3 Table 24: Inventory results (10% FA), average values for concrete types (Kg CO_2-eq/m³ RMC)

Concrete Types	Cement & Mineral Additives Production	Chemical Admixtures Production	Aggregate Production	Resources Transport	Concrete Batching	Ready-Mix Concrete Transport	10% FA
	CP+MA	CAP	AGP	Re´sT	RMCP	RMCT	ARM
Strength Class	201.5	1.4	6.2	11.3	4.9	5.3	230.6
Maximum w/c ratio	249.6	2.5	6.2	12.1	5.0	5.3	280.6
Maximum w/c and Air	255.2	2.4	6.0	11.9	5.0	5.3	285.7
Frost tested	324.1	2.8	6.0	23.2	5.0	5.3	366.4
Self-Compacting Concrete	230.8	4.8	5.4	16.4	5.0	5.3	267.6

10.4.4 Table 25: Inventory results (20% FA), average values for concrete types (Kg CO_2-eq/m³ RMC)

Concrete Types	Cement & Mineral Additives Production	Chemical Admixtures Production	Aggregate Production	Resources Transport	Concrete Batching	Ready-Mix Concrete Transport	20% FA
	CP+MA	CAP	AGP	Re´sT	RMCP	RMCT	ARM
Strength Class	191.2	1.4	6.1	11.9	4.9	5.3	220.8
Maximum w/c ratio	240.9	2.4	6.0	13.0	5.0	5.3	272.6
Maximum w/c and Air	243.3	2.4	5.9	12.7	5.0	5.3	274.5
Frost tested	309.3	2.8	5.8	23.7	5.0	5.2	351.9
Self-Compacting Concrete	218.0	4.8	5.4	17.3	5.0	5.3	255.7

10.4.5 Table 26: Inventory results (25% Slag), average values for concrete types (Kg CO_2-eq/m^3 RMC)

Concrete Types	Cement & Mineral Additives Production	Chemical Admixtures Production	Aggregate Production	Resources Transport	Concrete Batching	Ready-Mix Concrete Transport	25% Slag
	CP+MA	CAP	AGP	Re´sT	RMCP	RMCT	ARM
Strength Class	164.1	1.3	6.6	13.4	4.9	5.3	195.4
Maximum w/c ratio	211.1	1.7	6.5	14.8	4.9	5.3	244.1
Maximum w/c and Air	213.9	2.2	6.3	14.6	4.9	5.3	248.8
Frost tested	273.2	2.4	6.3	24.4	5.0	5.3	316.6
Self-Compacting Concrete	196.6	4.8	5.4	19.4	5.0	5.3	236.4

10.4.6 Table 27: Inventory results (50% Slag), average values for concrete types (Kg CO_2-eq/m^3 RMC)

Concrete Types	Cement & Mineral Additives Production	Chemical Admixtures Production	Aggregate Production	Resources Transport	Concrete Batching	Ready-Mix Concrete Transport	50% Slag
	CP+MA	CAP	AGP	Re´sT	RMCP	RMCT	ARM
Strength Class	135.2	1.3	6.6	15.1	4.9	5.3	168.4
Maximum w/c ratio	177.4	1.6	6.5	16.3	4.9	5.3	212.0
Maximum w/c and Air							
Frost tested							
Self-Compacting Concrete	168.6	4.8	5.4	21.5	5.0	5.3	210.6

10.4.7 Table 28: Inventory results (100% Slag), average values for concrete types (Kg CO_2-eq/m^3 RMC)

Concrete Types	Cement & Mineral Additives Production	Chemical Admixtures Production	Aggregate Production	Resources Transport	Concrete Batching	Ready-Mix Concrete Transport	100% Slag
	CP+MA	CAP	AGP	Re´sT	RMCP	RMCT	ARM
Strength Class	103.6	1.3	6.6	17.3	4.9	5.3	139.0
Maximum w/c ratio	132.2	1.5	6.4	19.9	4.9	5.3	170.1
Maximum w/c and Air							
Frost tested							
Self-Compacting Concrete	129.2	4.8	5.4	24.2	5.0	5.3	174.0