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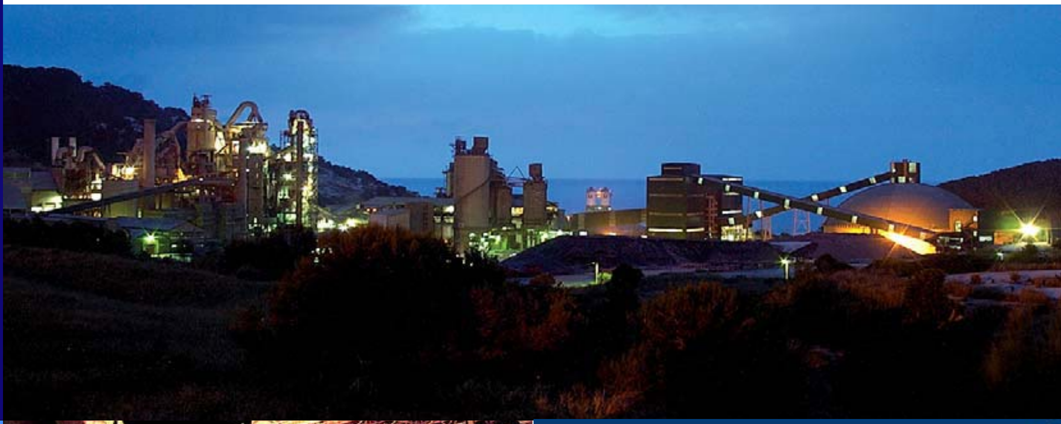
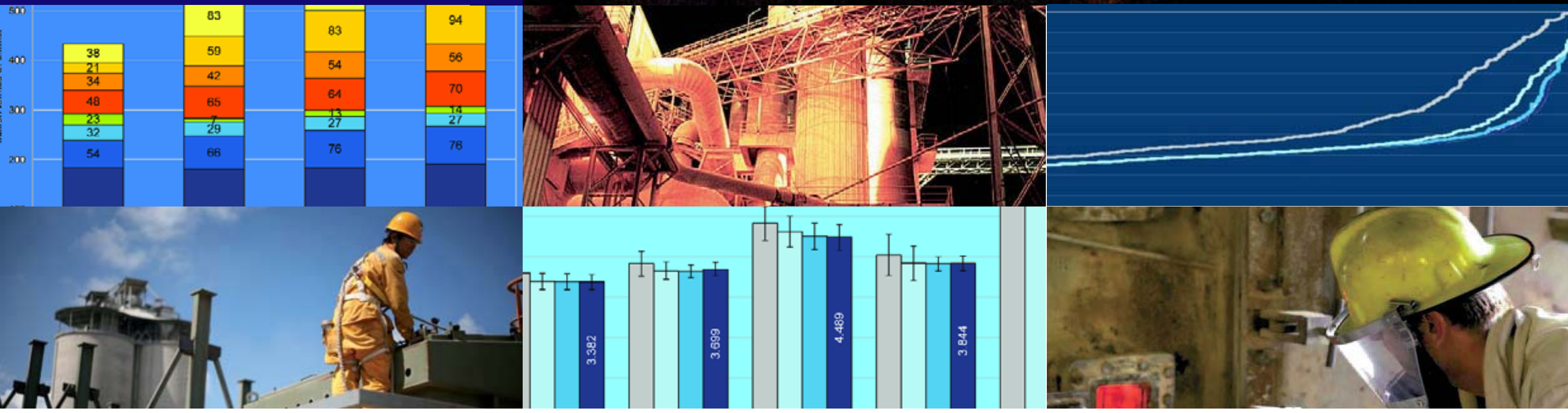
The Cement Sustainability Initiative





Cement Industry Energy and CO_2 Performance

“Getting the Numbers Right”

World Business Council for
Sustainable Development

Contents

Note

This report has been produced within the framework of the WBCSD’s Cement Sustainability Initiative (**WBCSD CSI**) and is provided solely for the information of both WBCSD-CSI-Member participants and non-WBCSD-CSI-Member participants (collectively the **Participants**) in the “*Getting the Numbers Right*” project (the **Project**) as well as the cement industry’s major stakeholders. The information presented and the analysis performed in this report are based on data provided exclusively by the Participants in the Project. Since the Project, however, does not yet include the cement industry worldwide, not all of the regions are equally well covered. This places some limits on the report’s analysis and conclusions for certain regions, particularly Asia, countries in the Commonwealth of Independent States (CIS), Africa, Middle East and Japan/Oceania). The terms ‘cement’, ‘cementitious’, ‘gross emissions’ and ‘net emissions’ are used following definitions in the WBCSD CO_2 Reporting Protocol (described in the Glossary); it is understood that other reporting schemes may use different definitions for these terms.

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1 Executive summary

A Cement Sustainability Initiative project begins

In 2007-2008, the Cement Sustainability Initiative (CSI), operating under the umbrella of the World Business Council for Sustainable Development (WBCSD), developed the "Getting the Numbers Right" (GNR) system for its members.

GNR is a CO_2 and energy performance information system, based on emissions data from individual cement plants. It aims to develop representative statistical information on the CO_2 and energy performance of clinker and cement production worldwide. The CSI initiated the GNR project to respond to internal and external stakeholder requests for reliable, up-to-date CO_2 emissions data from the industry. The CSI recognized that having accurate and detailed data would enable its members to identify the factors and levers that can impact those emissions, and use this information to develop practical climate mitigation strategies.

This report

This report covers the period 1990 to 2006. It outlines the GNR system in more detail, and shows how an effective measuring, reporting and verification (MRV) system can be developed and managed for and by industry. The system includes information from 844 cement installations worldwide, covering over 73% of cement production in Kyoto Annex 1 countries. Whereas many multinational companies participate in the project, coverage in non-Annex 1 countries is only around 20% due to the absence of many other companies, mainly in China. The CSI continues to work on increasing GNR coverage around the world, and therefore improving the representativeness of the GNR system.

Cement and CO_2

Concrete is an essential building material for society's infrastructure around the world. **Concrete** is second only to water in total volume produced and consumed annually by society. **Cement** is the essential "glue" in concrete and as such is used in increasingly significant volumes.

Clinker is an intermediate product made during the cement manufacturing process-–a hard, stone-like material that is eventually cooled and ground to become cement. The decomposition of the raw material, limestone, creates most (about 60%) of the cement industry's direct CO_2 emissions. The remaining direct emissions originate from burning fuel during the manufacturing process to reach the high temperatures necessary for clinker formation. Indirect emissions from electric power consumption contribute another 10% to overall CO_2 emissions (see section 8.2 for more information).

1. Industry performance: emissions

The cement industry has achieved a significant decoupling of economic growth and absolute CO_2 emissions. Cement production by GNR companies has increased by 53% from 1990 to 2006, whereas the absolute net CO_2 emissions increased by only 35%. The rate of decoupling between production and net emissions is increasing, but this trend cannot, of course, continue indefinitely.

Each factor or lever that impacts CO_2 emissions and energy efficiency can be quantified by an individual performance indicator, including: average thermal efficiency per tonne of clinker, substitution of conventional fuels by alternative fossil fuels and biomass. Overall performance on those levers can be shown by measuring gross and net CO_2 emissions per tonne of clinker (for specific emissions, see glossary). For example, in 2006, the GNR global average gross specific CO_2 emissions were 866 kg CO_2 / tonne of clinker.

One lever to improve efficiency is to address product composition – a process called clinker substitution. This entails blending materials with cement to reduce the volume of clinker used. Such materials include blast furnace slag and coal fly ash from other industries, natural volcanic material and limestone. The resulting product contains several mineral components and is often called Portland composite cement or blended cement. The GNR global average net CO_2 emissions per tonne of cementitious product in 2006 was 660kg.

To summarize, in the context of this report, the broader term "cement" includes all hydraulic binders that are delivered to the final customer, i.e., all types of Portland, composite and blended cements plus ground granulated slag and fly ash, to be used as clinker substitutes in ready-mix (pre-mixed concrete).

"Cementitious product" excludes clinker purchased from another company and used to make cement. Cement is equal to cementitious when the net balance of clinker sold and purchased is equal.

2. Industry performance: using waste materials

The cement industry can offer an eco-efficient solution for some of society's waste by using it as an alternative source of energy and minerals, at the same time reducing some of its own fuel-related emissions. In 2006, GNR participants recovered 13 million tonnes of waste, which provided 10% of their thermal energy needs. There are large differences in alternative fuel use across regions, ranging from zero to 70% of total fuel requirements. Higher usage occurs in countries with better developed environmental legislation, law enforcement, waste collection and management practices. Recovering the thermal and mineral content of waste in cement helps reduce greenhouse gas emissions at waste landfills and in incinerators.

Moving forward

The WBCSD Cement Sustainability Initiative "Getting the Numbers Right" (GNR) system contains a wealth of information that can be used by stakeholders wanting to understand how the industry is monitoring and addressing its emission trends. To use information from the GNR system or make specific queries about the data, send requests to: gnrpmc@wbcsd.org (see section 7).

Table 1: GNR variables in 2006

Variable	Unit	2006	% change since 1990
Number of installations	Number	844	+ 17%
Clinker production	Mtonne of clinker	626	+ 44%
Cementitious product production	Mtonne cementitious product	801	+ 53%
Gross CO_2	Mtonne CO_2	544	+ 37%
Net CO_2	Mtonne CO_2	530	+ 35%
Gross CO_2 per tonne of clinker	kg CO_2/tonne of clinker	866	- 5.3%
Net CO_2 per tonne of clinker	kg CO_2/tonne of clinker	844	- 6.9%
Gross CO_2 per tonne cementitious	kg CO_2/tonne cementitious product	679	-10.6%
Net CO_2 per tonne cementitious	kg CO_2/tonne cementitious product	661	-12.1%
Clinker substitution	Clinker to cement ratio	78.0	- 5.9%
Thermal energy efficiency	MJ/tonne clinker	3,690	-14%
Electric energy efficiency	MWh/tonne cement	111	- 3.5%

2 Introduction

In 2006, the WBCSCD Cement Sustainability Initiative (CSI) committed to developing a global and regional CO_2 and energy performance information system for the cement sector. The objective of the CSI “Getting the Numbers Right” (GNR) system was to develop representative statistical information on the CO_2 and energy performance of clinker and cement production worldwide and regionally to serve the needs of internal and external stakeholders. There are several pertinent reasons for developing a global database and for making this information available:

- To have accurate, up-to-date CO_2 emissions and energy performance data from the cement sector.
- To respond to the need for internal and external stakeholders’ to understand the cement industry’s CO_2 emissions, and the factors that could impact those emissions. The sector must be able to provide policy-making bodies and key stakeholders with an accurate, clear picture of its CO_2 emissions in order to work effectively towards reductions.
- To provide a sound analytical basis for emissions benchmark-setting.

Currently, all WBCSD CSI members participate in GNR by submitting CO_2 and energy performance data. Additionally, CEMBUREAU, the European cement association participates in GNR and has adopted the WBCSD/CSI CO_2 Protocol. It has collected information from non-CSI cement plants, ensuring nearly full participation of all cement installations in Europe.

Some other national and regional organizations have, or are in the process of developing, national or regional information systems (e.g., the Australian Cement Industry Federation (CIF), the Cement Association of Canada (CAC), and the Japan Cement Association (JCA)). A goal of the GNR system is to build an open platform for participation by other companies and organizations, managed by an objective third party, in order to build the broadest possible global and regional system for future analysis. Using the common protocol for monitoring and reporting, and a common methodology for data analysis, will ensure consistency in data input and will help provide reliable and broadly applicable output.

This report details key results from the years 1990, 2000, 2005 and 2006. Competition concerns require the collection of information only after a delay of 12 months. Two types of emissions values are reported here: gross and net. Figures for gross emissions are used in the report to show the full emissions from the sector (excluding biomass). Net emissions exclude emissions resulting from fossil alternative fuels (waste). This exclusion is made because burning wastes in a cement kiln avoids their disposal in landfill or an incinerator, and displaces an equivalent amount of fossil fuel that would otherwise be needed to make cement. The difference between gross and net emissions globally is approximately 4% of total emissions, although there are widespread regional variations as noted above.

3 Data

Collection and consolidation of data for the GNR system follows three main steps:

1. Each company participating in the GNR system collects information related to CO_2 emissions and energy consumption at facility, company and national levels, using the WBCSD/CSI CO_2 reporting protocol and reporting template.[1]
2. Each participating company, using a secured Internet data collection tool specifically designed for the GNR system, uploads its data to PricewaterhouseCoopers (PwC), the database owner and manager.
3. The PwC team performs the final consolidation and reporting phase, which involves implementing coherence checks and data consolidation at global and regional levels (see section 3.2).

Annex 1 gives an example of the Excel™ file template used to upload data. More graphs on GNR data are available on the CSI website.[2]

3.1 *Type of data collected*

CO_2 and energy performance data are collected on:

- Absolute gross and net CO_2 emissions[3]
- Specific gross and net CO_2 emissions per tonne of clinker and per tonne cementitious product
- Average thermal energy consumption per tonne of clinker
- Specific electric energy consumption as a kWh/tonne cement
- Fuel mix (fossil fuel/alternative fossil fuel / biomass)
- Clinker to cement ratio

To enable calculation of the percentiles, trend lines and correlations, company facilities are also required to provide:

- Location of installation
- Type of installation and kiln technology
- Production volumes for clinker, cement and cementitious products
- Differentiation by grey/white cement[4]
- Nominal capacity

The system also collects information on the type and degree of external assurance of data and system quality at plant and company level.

3.2 Quality of data collected

Collected data is only accepted into the GNR system following a series of quality control measures including:

1. Use of the WBCSD/CSI CO_2 reporting Protocol and automated extraction of selected Protocol results information
2. Assurance of company CO_2 data by an independent third party at least once every three years

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[1] *CO_2 Accounting and Reporting Standard for the Cement Industry* protocol and instructions are available from www.wbcsdcement.org/climate

[2] See www.wbcsdcement.org/CO2data

[3] See Glossary for precise definition

[4] Around 99% of global cement production is grey cement (ordinary Portland and various composite cements). Only 1% is white cement, for niche architectural applications. This report focuses on indicators related to grey cement.

3. A series of data quality checks to ensure coherence, accuracy and reasonableness

a. WBCSD/CSI Reporting Protocol

The WBCSD/CSI *CO_2 Accounting and Reporting Standard for the Cement Industry* was first developed in 2001-02 following principles outlined in work by the WBCSD and the World Resources Institute (WRI).[5] The ongoing purpose of this tool is to provide a common language, set of definitions and methodologies to estimate CO_2 emissions from cement production facilities. This version of the Protocol is specific to the cement industry, and includes tailored rules for accounting for different fuels and their carbon content, biomass, clinker substitutes and several Key Performance Indicators (KPIs). In addition, specific rules were developed to consolidate information from joint ventures and other partially owned holdings. This initial version of the Protocol was field-tested for two years, reviewed with other parties, and revised in 2005 based on comments received from both users and reviewers.

Initial data for the GNR system was taken from the years 1990, 2000, 2005 and 2006 to provide preliminary trend information. Early data is no doubt less reliable than from later years, as it has to be reconstructed from fifteen year old historical records of cement production, fuel purchases, company ownership etc. Data collected under the common WBCSD/CSI CO_2 reporting Protocol was first available in 2003.

b. Independent assurance

Individual CSI companies participating in GNR have agreed to independent third party limited assurance of their CO_2 emissions information, beginning in 2006. This assurance process is managed at a company level, and involves visits to a sample of a company's facilities (as determined by the assurance provider). Of the 2006 data submitted to the GNR, data representing 86% of production had been assured.

c. Data quality verification

Once data collection is complete, PwC performs a series of consistency checks to ensure that (a) data is correctly situated in the system, (b) values submitted fall within a range usually observed in the industry, and (c) data for all facilities have been supplied. Using an iterative process, PwC liaises with participant companies to assess the validity of data values that fall outside expected ranges. For unexplained anomalies the CSI has retained an independent third party cement industry specialist to provide anonymous expert review. If a suspect data point cannot be validated, the information is rejected.

3.3 Confidentiality of data and legal structure

To ensure non-disclosure of confidential information and compliance with anti-trust laws, an overarching legal and operating structure was developed to meet the goals of the program. The basic elements of this structure are outlined below.

a. Independent database owner and operator

Anti-trust law in Europe, the US and Japan requires that collection of business-sensitive information be properly managed to avoid disclosure to competitors. To ensure that no participant had access to any information but their own data and aggregated data, an independent third party service provider was retained to develop the database, including providing appropriate IT security measures for data input and output, data checking procedures, etc.

After a competitive bidding process, PwC was selected for this work. PwC developed the database system, collates reported data, analyzes the results of

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[5] CO_2 Accounting and Reporting Standard for the Cement Industry, www.wbcsdcement.org/climate

various statistical queries, and produces consolidated data and reports. Data is uploaded and reports are downloaded through a secure website.

As the independent manager of GNR, PwC is responsible for ensuring that all data that can be traced back to individual companies or plants will not be disclosed, nor be accessible to any unauthorized internal or external stakeholder. PwC also provides a guarantee of non-disclosure of confidential information and compliance with competition law including when reviewing and responding to query requests. Within PwC, IT audits are regularly undertaken to ensure adequate security and performance of the IT structure.

In addition, a Project Management Committee was set up to serve as the single contact point for all communications between participants in the GNR system and PwC. The Committee develops the schedule for companies' data submittal to PwC and receives and approves or rejects stakeholder queries.

b. Key documentation

PROJECT AGREEMENT

A Project Agreement was established between PwC and the WBCSD. It establishes the name and objectives of the project, scope of work, PwC's obligations and participating organizations, intellectual property rights of the input data and output results, fees and expense structure and payment terms, a capped indemnification for damages for any participant, typical contractual terms such as duration, termination terms, and legal regime.

INDIVIDUAL SERVICE AGREEMENT

Each participating organization must have a service agreement with PwC to address confidentiality, governing law and basic items identified in the Project Agreement. Working with outside counsel, the CSI provided an example of typical terms and provisions for each CSI company to use, although each company retained the right to negotiate specific terms with PwC. This approach was taken to minimize both the costs and time period necessary to reach workable agreements with the 18 CSI companies. In almost every case, the company and PwC adopted the typical terms.

Annexes to the Individual Service Agreement include a **CONFIDENTIALITY AGREEMENT**, a **CODE OF CONDUCT** and the **PROJECT MANAGEMENT CHARTER**. The latter defines the general framework for managing the program and governance rules for interactions between PwC and the participants. Again, to minimize lengthy and costly negotiations, each participant agreed to use the identical terms for the Confidentiality Agreement and the Code of Conduct.

The CSI is willing to share the legal documents developed for this project with others interested in establishing similar industry data collection and analysis programs. Interested parties should contact the Project Management Committee at: gnrpmc@wbcsd.org

4 GNR coverage and cement production

4.1 GNR coverage and representativeness

a. Coverage

The GNR system currently includes information from 43 multinational or national cement companies, totaling 844 installations (2006 figures). Of these, there are 615 grey cement production facilities, 179 grinding stations, 30 white cement production facilities, and 20 "other" facilities (plants producing cementitious without the use of clinker). In total, these installations produced 801 million tonnes of cementitious product in 2006.

Whereas the GNR system is the only cement industry CO_2 and energy database with global coverage, it does not yet include the total cement industry worldwide, and its level of coverage and representativeness varies across regions.

Regional coverage and representativeness of the system can be estimated referring to the cement production volumes reported by the United States Geological Survey (USGS).[6] The GNR system has almost complete coverage for Europe and represents over two-thirds of production in the Americas and around 40% in India, Africa & the Middle East and Japan-Australia-New Zealand.

However, representativeness is still limited or unknown for the Commonwealth of Independent States (CIS) and China. It is difficult to quantify the global and Asian coverage of the system because the availability and reliability of information on total cement production in large parts of Asia, notably China, is limited.

The information from 1990 to 2006 is comparable over time. The system includes information for 1990, 2000, 2005 and 2006 provided the installations were in operation during at least one of those years. When an installation was closed during the 1990–2006 period, historic information from prior to the closure remains in the GNR system. When a GNR participant acquired an installation, then the pre-acquisition information is also included in the system. Throughout the report, the 1990 baseline has been normalized, i.e., adjusted to take into account acquisitions and divestments. All participants' installations are fully accounted for in GNR and measures have been taken to prevent double counting (in case of joint ownership by two or more companies).

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[6] United States Geological Survey 2005 data on global cement production by country is updated annually and is available at: http://minerals.usgs.gov/minerals/pubs/commodity/cement/cemenmyb05.pdf

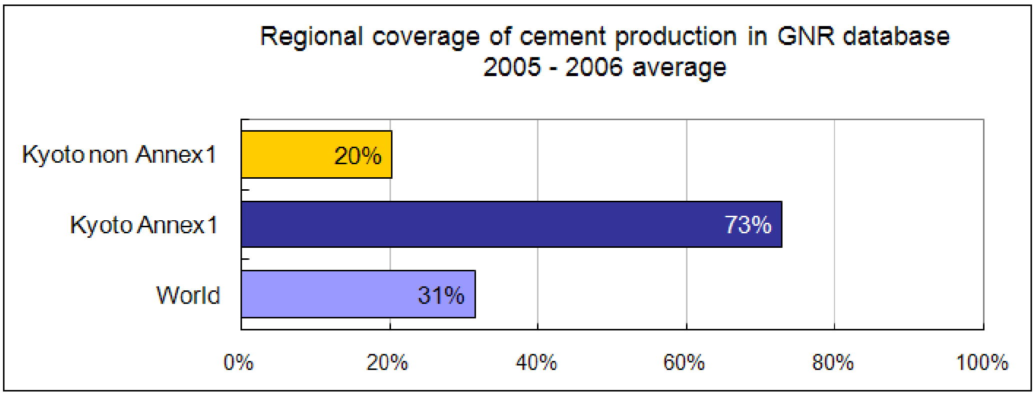


Figure 4.1: Regional coverage of cement production in the GNR database

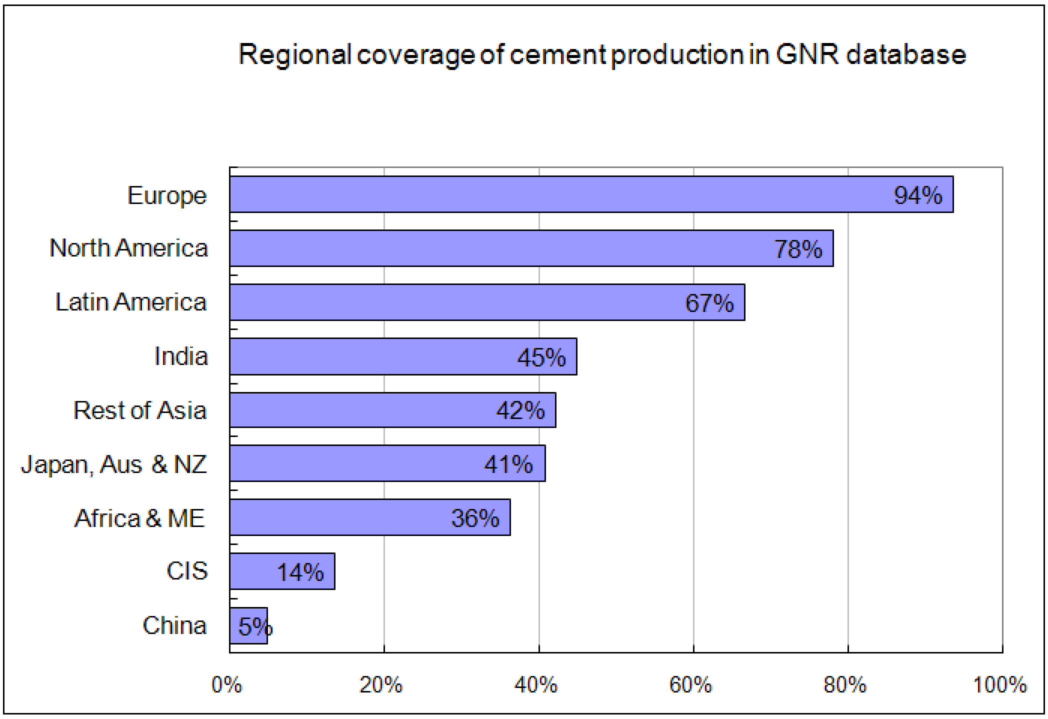


Figure 4.2: Regional coverage of cement production in the GNR database

b. Data coverage

With current coverage, absolute volumes – such as those of production, CO_2 emissions and alternative fossil fuel and biomass use – refer only to the companies participating in GNR.

These companies form the large majority of the cement market in Annex 1 regions, giving high coverage there. Although they include many multinational companies in non-Annex 1 regions, coverage is lower in non-Annex 1 countries and therefore it is possible that the emissions profile of GNR participants may not be representative of the complete cement industry in some regions.

The CSI aims to increase GNR coverage around the world, and therefore increase the representativeness of GNR data.

4.2 Production and related emissions

Figures 4.3 and 4.4 show production volumes for clinker and cementitious products of GNR participants in Annex 1 and non-Annex 1 regions from 1990 through 2006.

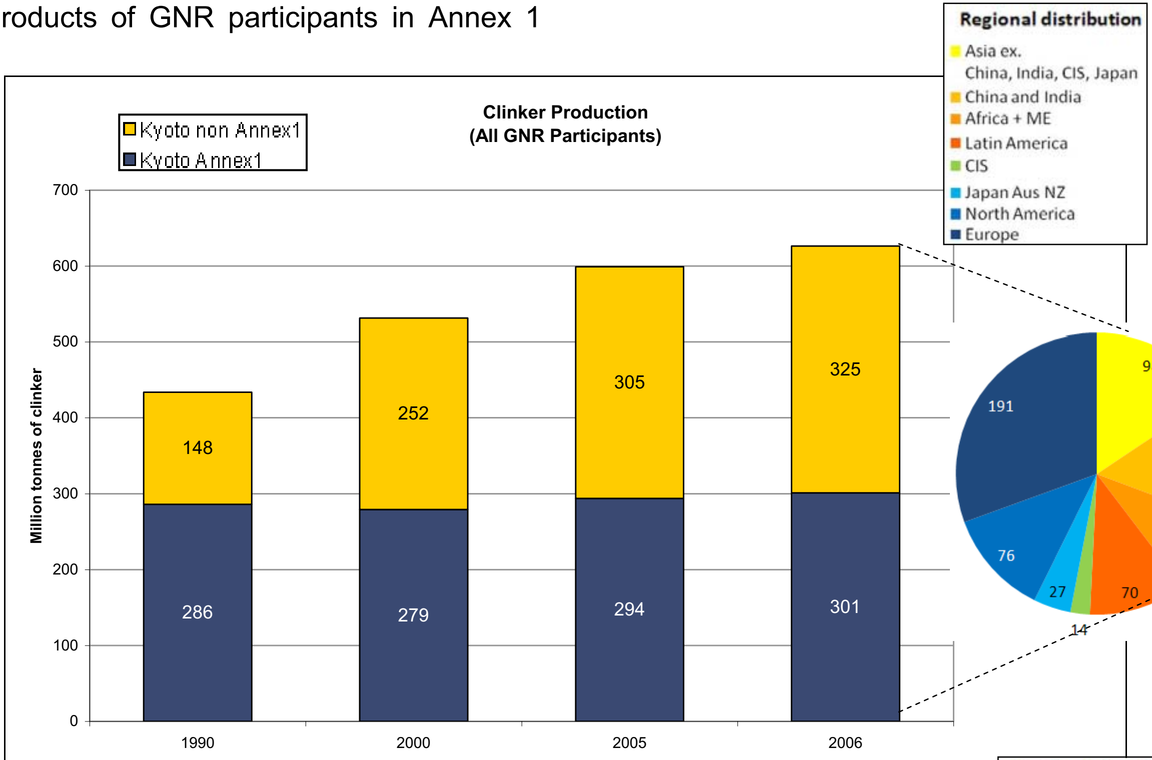


Figure 4.3: Clinker production by GNR participants over time (above)

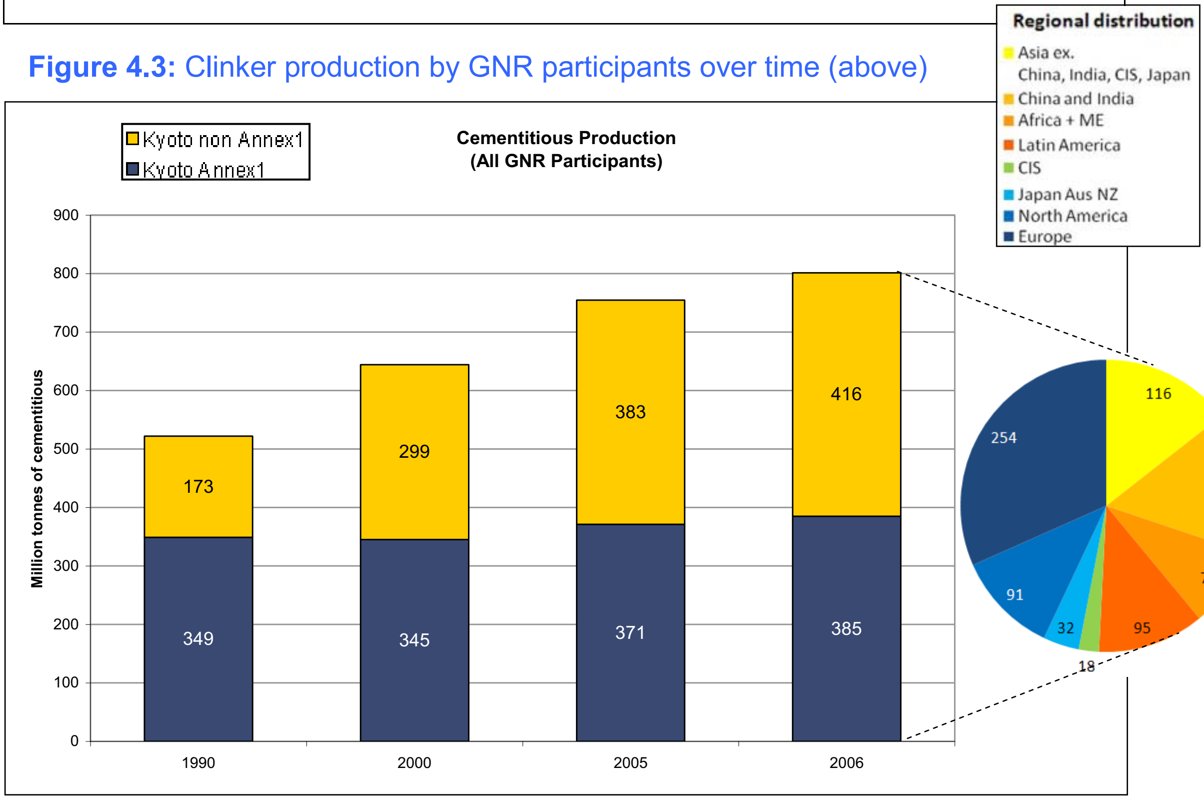


Figure 4.4: Cementitious production by GNR participants over time

The CO_2 Reporting Protocol indicators refer separately to clinker and cementitious products. GNR shows that clinker and cementitious production by GNR participants in Annex 1 regions in general has reached a plateau, while in non-Annex 1 regions, growth rates are significant. Historical trends show that demand for cement is initially driven by increases in economic development and population. Above a certain level of economic development, demand for cementitious tends to stabilize or decrease.

In Annex 1 regions, clinker and cementitious production remained flat between 1990 and 2000, largely as a consequence of negative growth in the former USSR, Japan and Oceania and because of growth stabilization in Europe. From 2000 to 2006 there was low growth - approximately 1% per year - except in Japan where production declined. This was partially compensated for by growth of approximately 25% in North America.

Growth is prominent in Asia, a reflection of the expansion of the Asian market and increased participation of multinational companies there. Development in Latin America has been quite different, with stabilization of production from 2000 to 2006. Production in Africa and the Middle East has grown steadily.

It is noteworthy that cementitious production volumes experience faster growth than clinker production in all regions. In Europe and Latin America, for example, the growth of cementitious production between 2000 and 2006 was double that of clinker production.

4.3 Reduction trends

GNR data shows a significant decoupling of CO_2 emissions and cement production. While cement production grew 10% from 1990 to 2006 in Annex 1 regions, absolute gross CO_2 emissions remained almost unchanged and absolute net CO_2 emissions decreased by 2.7%. In non-Annex 1 regions, cement production grew by a factor of 2.4 from 1990 to 2006, whereas absolute CO_2 emissions grew by a factor of slightly below 2.1.

While the period 1990 to 2006 saw a slight decrease in absolute gross and net CO_2 emissions in Europe, Japan and Oceania, absolute emissions increased in all other regions. Figure 4.5 shows the evolution of global absolute cement production together with global absolute net CO_2 emissions. The cement industry has achieved a significant partial decoupling of economic growth, represented by the cement production and absolute CO_2 emissions.

Whereas cement production by the companies participating in GNR increased by 53% in 2006, absolute net CO_2 emissions increased by only 35%.

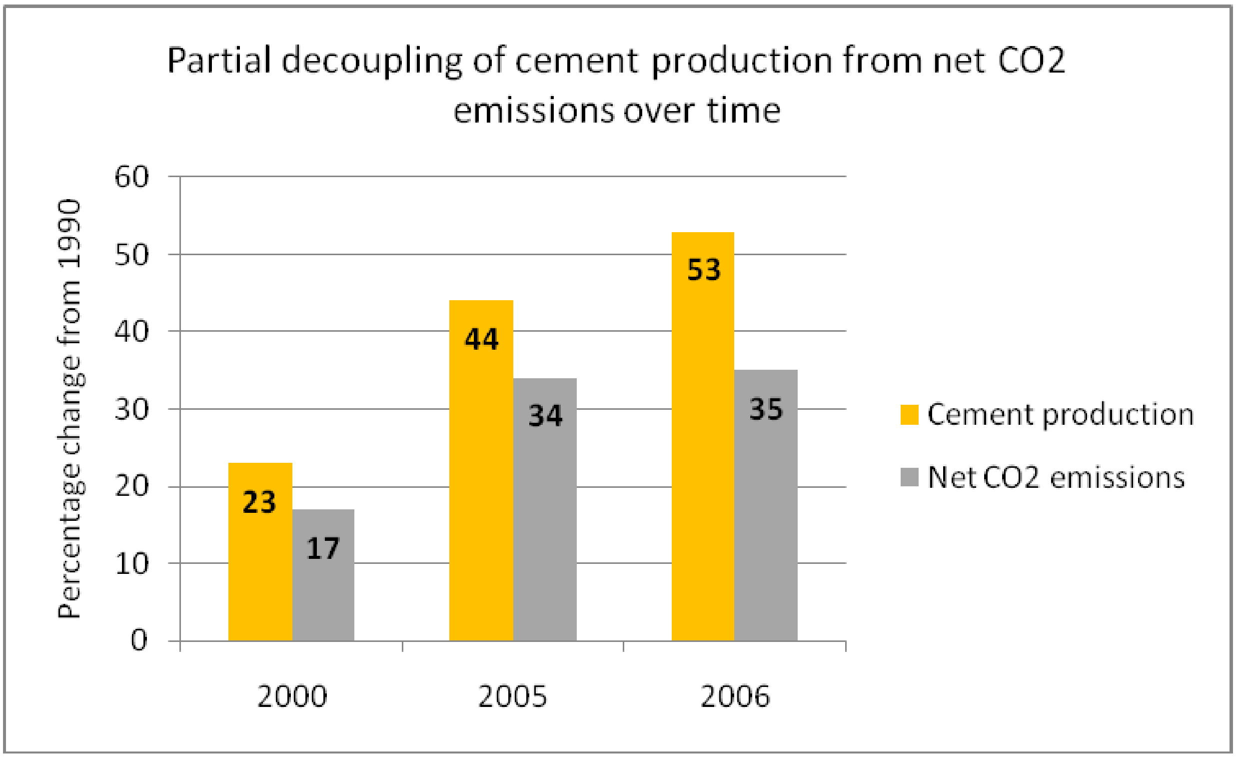
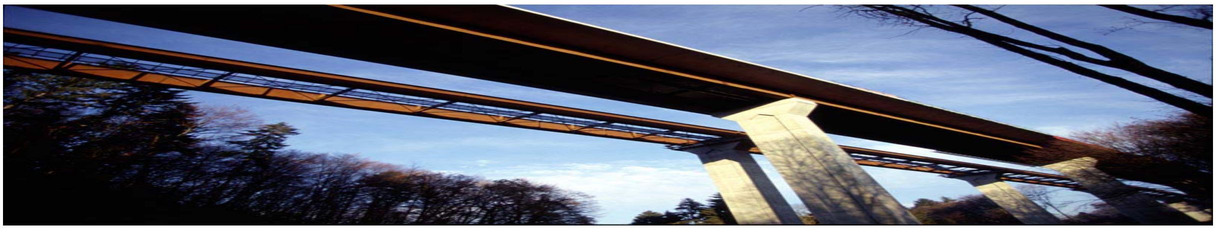


Figure 4.5 Global cement production and net CO_2 emissions

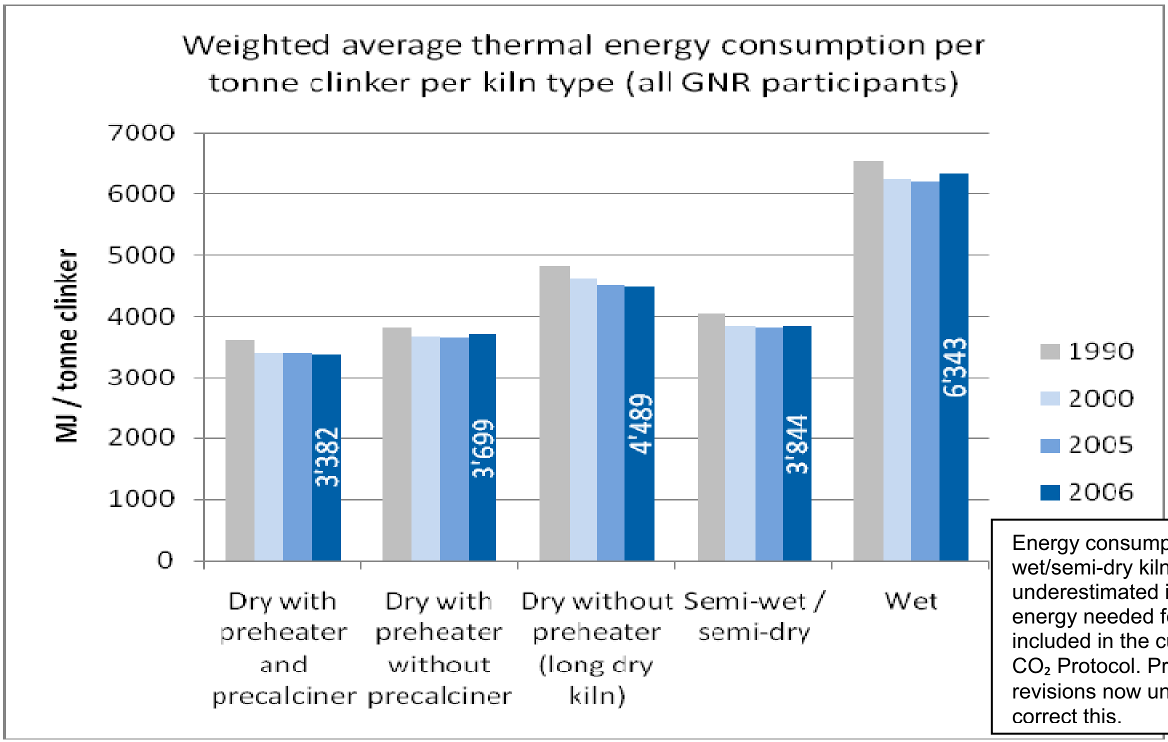
Despite improved emissions efficiency, wherever the growth of market demand for concrete and cement outpaces the technical potential to reduce CO_2 emissions per tonne of product, absolute CO_2 emissions will continue to increase.



5 Performance data

5.1 Thermal energy efficiency and kiln technology

Figure 5.1 gives the worldwide average thermal energy consumption per tonne of clinker for the different kiln types as a function of time, and including the variation of performance within each technology type. When building new plants, manufacturers install the most recently developed technologies, which are also typically the most efficient. The more efficient technology typically provides a cost advantage to the producer through reduced energy costs. Therefore, efficiency does increase gradually over time through new technology developments. However, installing cleaner technologies alone does not automatically provide the highest possible emissions reductions. After installation, machinery must be operated efficiently and maintained correctly to ensure that the maximum potential savings are achieved. This "operational efficiency" varies by technology, and is hard to measure, but is an important aspect of emissions management.



Energy consumption for semi-wet/semi-dry kilns is underestimated in this chart, as energy needed for drying is not included in the current CSI CO_2 Protocol. Protocol revisions now underway will correct this.

Figure 5.1: Weighted average thermal energy consumption per tonne of clinker per kiln type

The best energy efficiency – 3,380 MJ/tonne of clinker – is achieved with preheater kilns with precalciner (PH-PC), followed by preheater kilns without precalciner (PH), which are on average ~9% less efficient. The variation of performance within each technology is around 5%. Modern PH-PC kilns have a higher production capacity than older installations, which also contributes to higher energy efficiency across the board.

These values for PH-PC and PH kilns are about 500 to 600 MJ/tonne or 15% higher than reported by the IEA.[7] The values reported here are “working” annual average energy efficiencies, achieved in normal production operations reflecting normal operational variations caused by maintenance shut-downs and start-ups, variation in burning conditions, material humidity, etc. The values reported by IEA however are values typically achieved during initial commissioning tests by equipment suppliers. The normal operational energy consumption is around 15% higher than the best performance achievable during commissioning tests.

Long dry kilns without preheater towers consume around 33% more thermal energy and the old wet kilns consume up to 85% more energy than in PH-PC kilns.

There was very little or no improvement in average thermal efficiency per kiln type between 2000 and 2006.

It is uncertain whether the slight improvement from 1990 to 2000 has been a real improvement or is rather a consequence of limited reporting accuracy in 1990. These data show that the potential to improve the thermal efficiency of existing kilns through operational optimization is very small. Substantial improvement of the industry average thermal efficiency can only be achieved by investment in new or upgrading old kilns, assisted by closure of the less efficient installations. The thermal efficiency of an installation is largely defined by its original engineering design.

The slight increase in energy use in some kiln types in 2006 could possibly be a consequence of the increased use of alternative fossil fuels and biomass as a fuel. Indeed humidity in alternative fossil fuel and biomass requires additional heat and the combustion of coarse alternative fuels requires higher “excess” oxygen to ensure complete fuel combustion. It should be noted that for long dry kilns and semi-wet/semi-dry kilns the data base is rather weak because these kiln types are a small percentage of total production, therefore the resulting numbers may not be representative.

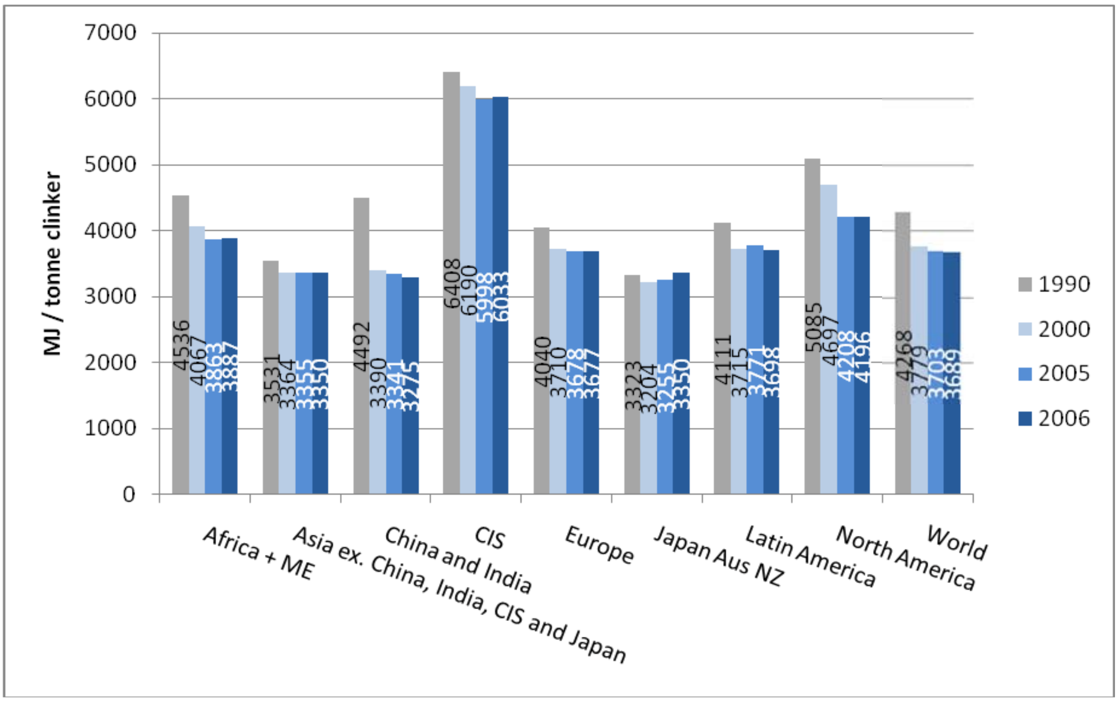


Figure 5.2: Regional thermal energy consumption over time

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[7] International Energy Agency (IEA 2007): ‘Tracking Industrial Energy Efficiency and CO_2 Emissions’, Figure 6.1.

a. Regional thermal energy efficiency

Figure 5.2 gives the average thermal energy consumption (MJ) per tonne of clinker at global and regional levels. Regional differences in average thermal efficiency can result from varying ages of installations and applied technologies, and different turnover and asset renewal times.

The average thermal efficiencies of China-India, Japan-Australia-NZ, and the rest of Asia are very close to the thermal efficiency of the most efficient PH-PC kiln technology. Indeed the large majority of clinker production in Japan and Australia is in PH-PC kilns. Japan invested in an accelerated renewal of its industrial assets to cope with the energy crisis of the 1970s. The large majority of CSI company kilns in China, India and rest of Asia are preheater kilns with or without precalciner, reflecting the growing cement market and relatively young assets in Asia. The GNR system is, however, as noted in chapter 4, not representative of China and the rest of Asia as a whole because many local companies do not yet provide data to the system.

At the other extreme, most kilns in the CIS region are still old wet kilns - fuelled with low-priced local natural gas - leading to a regional average thermal consumption of more than 6,000 MJ/tonne of clinker, almost 80% higher than the rest of Asia.

Also the North American average thermal consumption of 4,200 MJ/tonne is 25% above good practice due to an asset base with a relatively large number of wet, semi-wet and long dry kilns. The asset renewal has been slow in North America not only due to the relatively low energy prices but also due to the complex and lengthy permitting procedures for new kilns, and lengthy court and appeal procedures.

The average thermal consumption in Europe is about equal to the global average and around 10 % higher than best practice. The European asset base is characterized by a fairly high proportion of preheater kilns without precalciner, and a lower number of semi-wet and wet kilns. The average size of kilns in Europe and North America is around 0.9 to 1.1 million tonnes of clinker production per PH-PC kiln, compared to 1.9 million tonnes of production per site in Asia and around 0.5 to 0.7 million tones of production per site for other technologies. Larger kilns tend to have smaller heat losses per unit of product output.

Apart from North America, where historically specific heat consumption is very high, there has not been a significant improvement of regional average thermal efficiency in the period 2000 to 2006.The average thermal efficiency is about 10% better in the non-Annex 1 region than in the Annex 1 region, reflecting the generally newer, more efficient equipment in non-Annex 1 countries.

The global picture of clinker production per kiln type (Figure 5.3) shows a progressive shift towards dry process technologies with pre-heater and precalciner systems from 1990 to 2006. This technology represented 63% of the clinker produced in 2006 compared to 35% in 1990. Over the same period, the proportion of clinker produced with a wet process technology decreased from 16% to 5.6%. This change in the GNR database is primarily due to the increasing share of clinker production in the Asia region where multinational companies invest essentially in dry kiln technologies, and less a result of asset renewal in the mature countries.

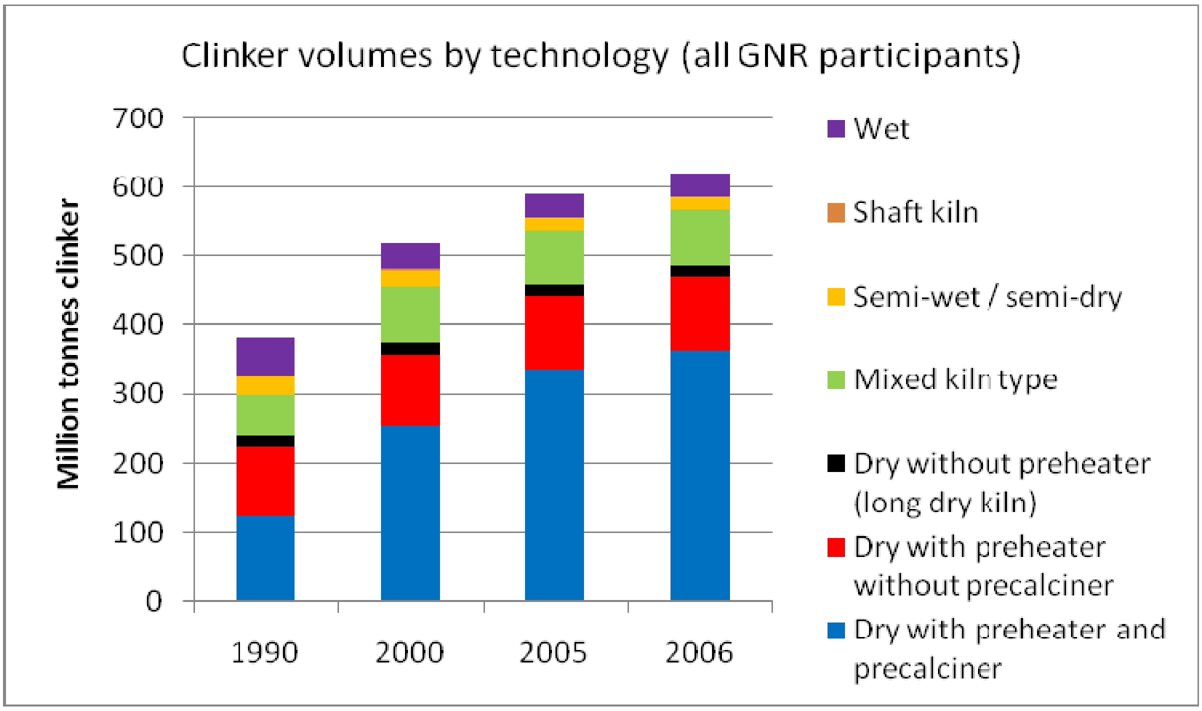

Figure 5.3: Clinker volumes by technology

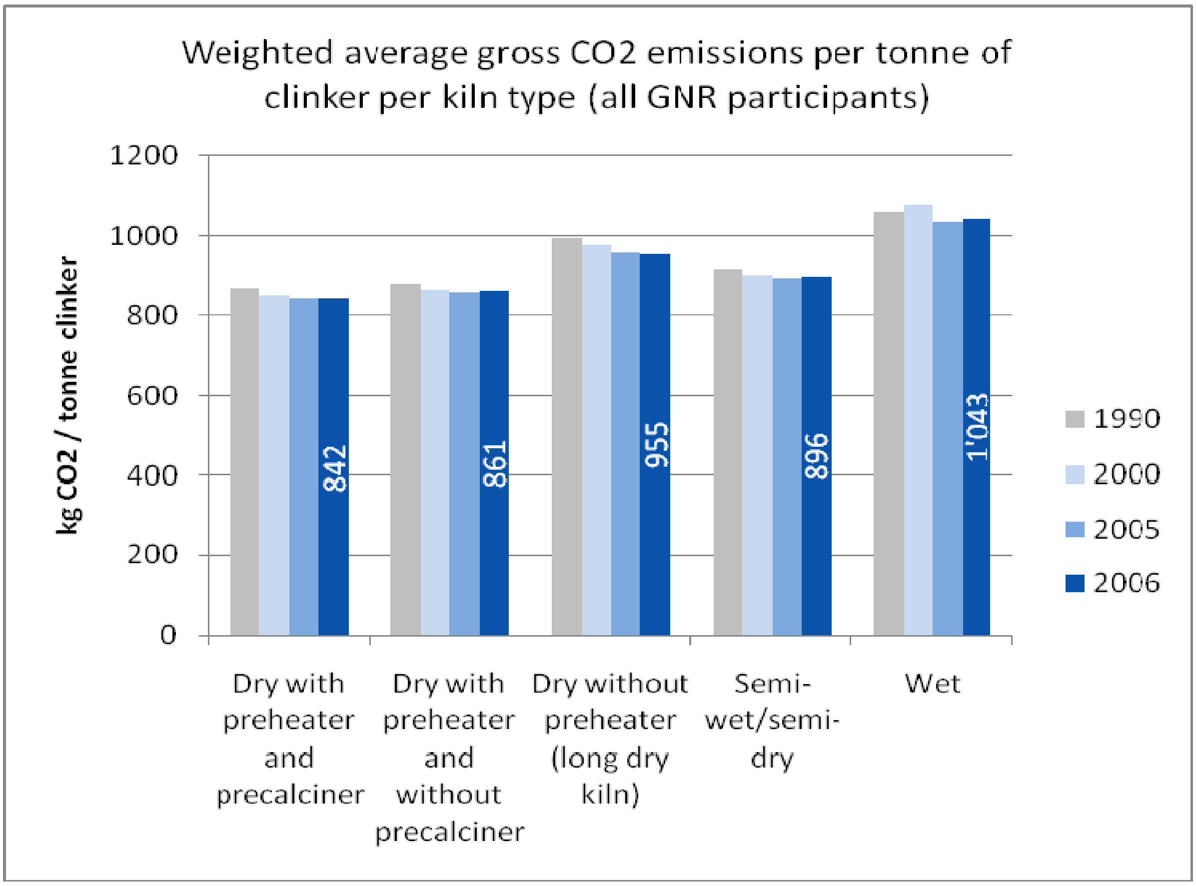

Figure 5.4: Global gross CO_2 emissions per tonne of clinker per kiln type

5.2 Fuel mix, alternative fossil fuels and biomass

Traditionally, solid fuels such as coal, petroleum coke (petcoke) and lignite were used in the burning process in clinker kilns. However, clinker kilns are particularly well-suited for alternative fossil fuels and biomass, and these can be effective substitutes as they have lower CO_2 emissions than traditional solid fuels.

In general, increased use of natural gas in the cement industry cannot be considered a viable greenhouse gas mitigation option at a global scale; not only would natural gas compete with alternative, waste-derived fuels that offer similar or even greater emissions reduction potential in the cement industry, it also normally offers a higher reduction potential per unit of thermal energy if used in other sectors. Only in exceptional cases would a switch to natural gas be considered a suitable and environmentally superior option. For these reasons natural gas is only used in the cement industry under very particular (and limited) local (economic, supply or political) circumstances.

Typical alternative fossil fuels include: waste oil, used tires, plastics, solvents, refuse-derived-fuel (RDF), tank bottom sludges and contaminated earth. Biomass includes agricultural waste, sludge from biological wastewater treatment, rice husks, charcoal.

When considering gross emissions, alternative fossil fuels can be 20-25% less carbon intensive (gross) than traditional coal and petcoke. A life cycle assessment (LCA) shows that there are additional, indirect savings that justify using a 0 net emission factor for all alternative fuels. As noted, co-processing these alternative fuels in the cement industry prevents equivalent CO_2 emissions at waste incineration disposal installations. Finally, any mineral content in alternative fossil fuels is incorporated into the clinker matrix during its formation. Thus there is no residual ash and associated heavy metal disposal, such as is typically found in incinerators.

The use of waste as an alternative energy source varies widely across regions and countries, mainly influenced by the level of development of waste legislation, law enforcement, waste collection infrastructure, and local environmental awareness. Unsorted and sorted municipal waste contains carbon of fossil and organic origin. In the GNR system, those types of mixed wastes are categorized as alternative fossil fuel thus providing a conservative reporting of fossil CO_2 emissions.

In the Annex 1 region alternative fuel use is better developed, contributing 16% of energy needs in 2006 (mainly from fossil origin). In the non-Annex 1 region, however, only 5% comes from alternative sources nearly equally divided between fossil and biomass origin.

Increasing the use of alternative energy sources is a slow process, with on average about 0.9% improvement per year from 2000 to 2006 in Annex 1 and 0.5% per year in non-Annex 1 countries.

Further geographical analysis shows that alternative fuels contribute 20% of energy needed in European cement plants (15% fossil and 5% biomass). North America and Japan-Australia-NZ source 11% from waste, essentially alternative fossil fuel. In the non-Annex 1 regions, Latin America sources 10% alternative energy of which 6% fossil and 4% biomass. Asia has begun such sourcing and reached a 4% substitution rate in 2006, equally of fossil and biomass origin. In Africa, the Middle East and CIS, alternative energy sourcing is insignificant.

These apparently modest contributions from alternative energy sources and annual increases in thermal substitution rate do, however, represent important increases of the volumes of waste received and processed by the cement industry (Figure 5.5).

In 2006 GNR companies gave a useful application to 13 million tonnes of waste, equivalent to a 10-15% annual increase of absolute volumes from 2000 to 2006. This represents a significant service to society along with conservation of conventional energy resources. Figure 5.5 also shows that about 80% of these volumes are from alternative fossil fuel in the Annex 1 region compared to 60% fossil and 40% biomass in the non-Annex 1 region.

For more information on alternative fuels used in the cement manufacturing process, see www.coprocem.org, and www.wbcsdcement.org (Alternative Fuel Use and POPs emissions).

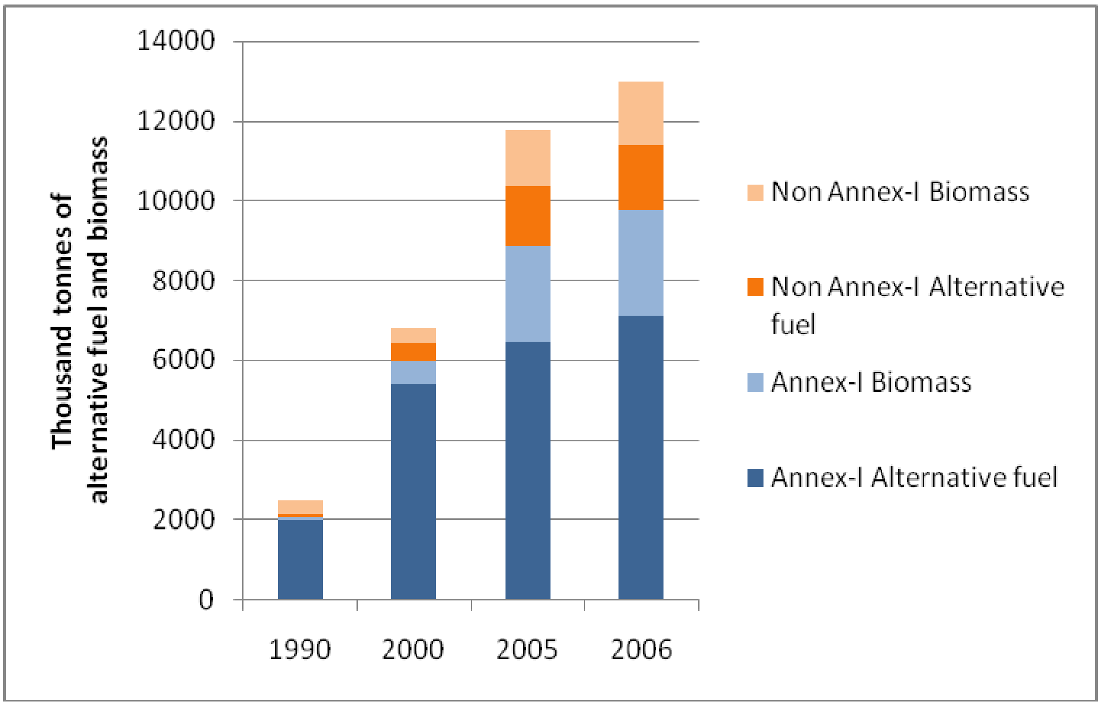

Figure 5.5: Absolute volumes of alternative fossil fuels

5.3 Gross CO_2 emissions per tonne of clinker

The spread in CO_2 intensity between kiln technologies is ~25% between the average wet and average preheater-precalciner kiln (Figure 5.4), compared to ~85% spread in thermal efficiency (Figure 5.1). The regional difference in gross CO_2 intensity per tonne of clinker is about 10% between the minimum (Japan-Australia) and the maximum (North America) compared to ~80% difference between minimum and maximum with thermal consumption. Whereas the thermal consumption in CIS is ~65% higher than the global average, its average gross CO_2 emission per tonne of clinker is only about 5% higher than the global average.

The reasons for these important differences are three-fold: process emissions, fuel mix and clinker mineralization. The CO_2 emissions from clinker kilns originate from two sources: the calcination of limestone, a chemical reaction in which limestone is converted into calcium oxide – “process emissions”, typically around 540 kg CO_2 per tonne of clinker (which is nearly constant) – and emissions from the combustion of fossil fuels. Between 0 and 10 kg CO_2 per tonne of clinker may originate from organic material in the limestone. The thermal efficiency of the clinker kilns only affects the fuel CO_2, but leaves process emissions unaffected. The thermal efficiency thus only affects on average ~40% of the emissions.

The dominant fuel in the CIS region is natural gas (widely available and inexpensive locally) with a CO_2 intensity per energy content of 56 kg CO_2 per GJ, compared with 93-96 kg CO_2 per GJ for coal and petcoke, which are the dominant fuels in most other regions, especially North America, Asia and Africa. Europe and Latin America also obtain significant fractions of their thermal needs from alternative fossil fuels and biomass. Some alternative fossil fuels have a CO_2 intensity of as low as 75-85 kg CO_2 per GJ, whereas CO_2 emissions from biomass are internationally considered as climate neutral, i.e., no CO_2 emissions.

Some cement companies in Latin America increasingly apply clinker mineralization. This process, using fluorides in the kiln, slightly decreases thermal consumption but is sometimes used to increase the lime saturation and clinker reactivity. Increasing the lime saturation and clinker reactivity slightly increases CO_2 emissions per tonne of clinker, but enables an additional ~5% decrease in clinker content in composite cement, resulting in lower CO_2 emissions per tonne of cementitious product and absolute CO_2 emissions

Global average gross CO_2 emissions per tonne of clinker was 866 kg CO_2 in 2006.

The spread in CO_2 emissions intensity between Annex 1 and non-Annex 1 is only 3%, compared to 10% for thermal consumption.

Figure 5.6 shows the global cumulative frequency distributions (CFD) of gross CO_2 emission per tonne of clinker for the four reporting years. CFD curves show, for the total production volume in a given region, the value of the performance indicator (vertical axis) versus the percentage of the total production (horizontal axis) that has a performance better than or equal to the corresponding value on the vertical axis. The decrease in emissions at the far (80%+) of the curves is indicative of the improving performance with time. See section 6 for more detail.

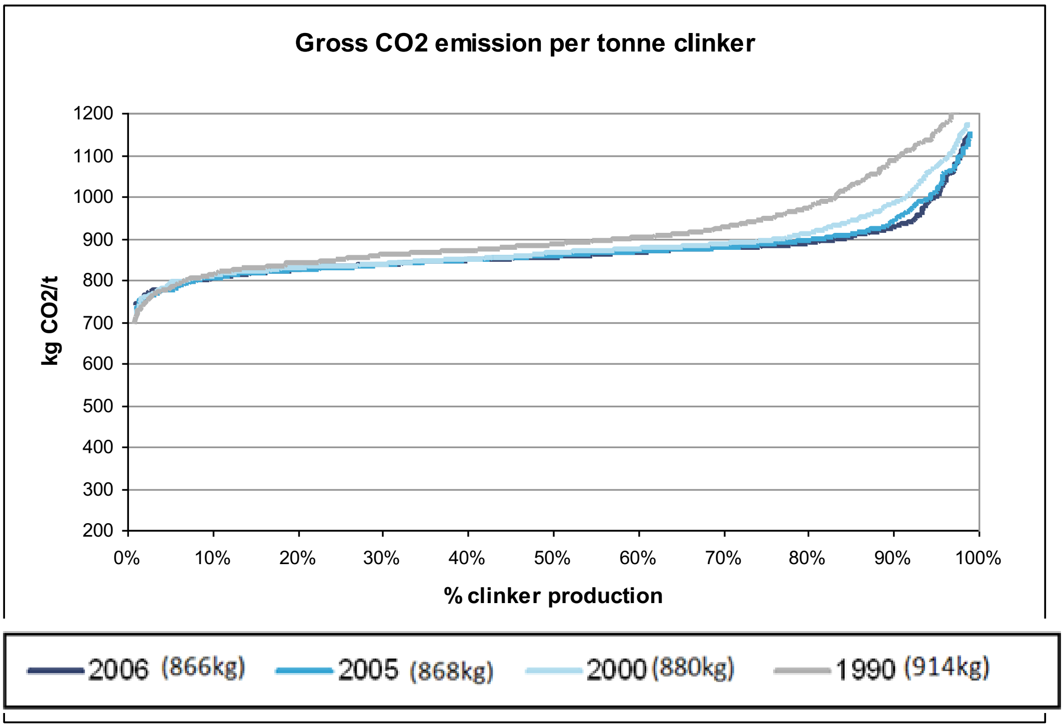

Figure 5.6: Gross CO_2 emissions per tonne of clinker

As noted earlier, net CO_2 emissions account for indirect savings resulting from the recovery of waste fossil fuel. In 2006, the global average net CO_2 emissions per tonne of clinker were 2.5% lower than gross emissions.

The difference amounts to 4.4% in the Annex 1 regions and 5.2% in Europe, where waste co-processing is more widely used. The difference between gross and net emissions in the non-Annex 1 region is less than 1%, indicative of a much smaller use of alternative fuels.

5.4 Clinker content in cement

Clinker is the main constituent in most types of cement. When it is ground and mixed with 4–5% gypsum it has hydraulic properties, i.e., it reacts with water and hardens. Other mineral components (MIC) also have hydraulic properties when ground and mixed with clinker and gypsum, notably ground granulated slag from blast furnaces, fly ash from coal fired power stations and volcanic or natural pozzolanic materials. Some limestone when ground together with cement also improves some properties of cement.

Those mineral components can be used to partially substitute clinker in cement, producing so-called Portland composite cements. The clinker content can vary between 10% and 90%, though the extremes are only applicable for special applications. Ordinary Portland cement (OPC) may contain up to 5% mineral components, and consequently contains between ~90% and 95% clinker and ~5% gypsum.

Different cement types have different properties, such as hardening time, early and late strength, resistance to salty conditions, heat release during curing, color, rheology and workability. The importance and applicability of those qualities depend on the application of the cement and concrete.

Substitution of clinker by mineral components reduces the volumes of clinker used, and therefore also the process, fuel- and power-related CO_2 emissions that occur during the clinker production. Composite cements thus have lower CO_2 emissions per tonne of cementitious product than OPC. The clinker to cement ratio is commonly used to report the degree of clinker substitution.

Mineral components can be used at different production stages (for cement and for concrete) according to local product standards, common practices and market situations.

Clinker substitution occurs mostly in the cement mill at the cement plant. The cement mill can be located either at the same site as the clinker kiln or on a different site, even in another country. In some countries and markets, ground mineral components are used at a mixing terminal or at the concrete mixer. To accommodate those different practices the CO_2 Protocol and GNR calculate the clinker factor and the CO_2 emissions per tonne of cementitious product at national company level instead of at clinker production level, and on the consolidated company basis of all types of installations, including clinker installations and separate grinding stations and terminals. However, in several countries cementitious materials are not delivered to the market by the cement industry, or are not available, which explains some of the differences in clinker factor between countries.

The market penetration of composite cement, and thus the potential for CO_2 specific emissions reductions, depends mainly on three aspects:

- Regional availability of clinker substituting materials
- National standards for OPC and composite cements
- Common practice and acceptance of the composite cements by construction contractors

Figure 5.7 shows the clinker to cement ratio for different regions. Practices vary around the world, with the lowest clinker factor in China-India, Latin America and Europe and the highest in North America and the CIS region and in Japan-Australia-NZ.

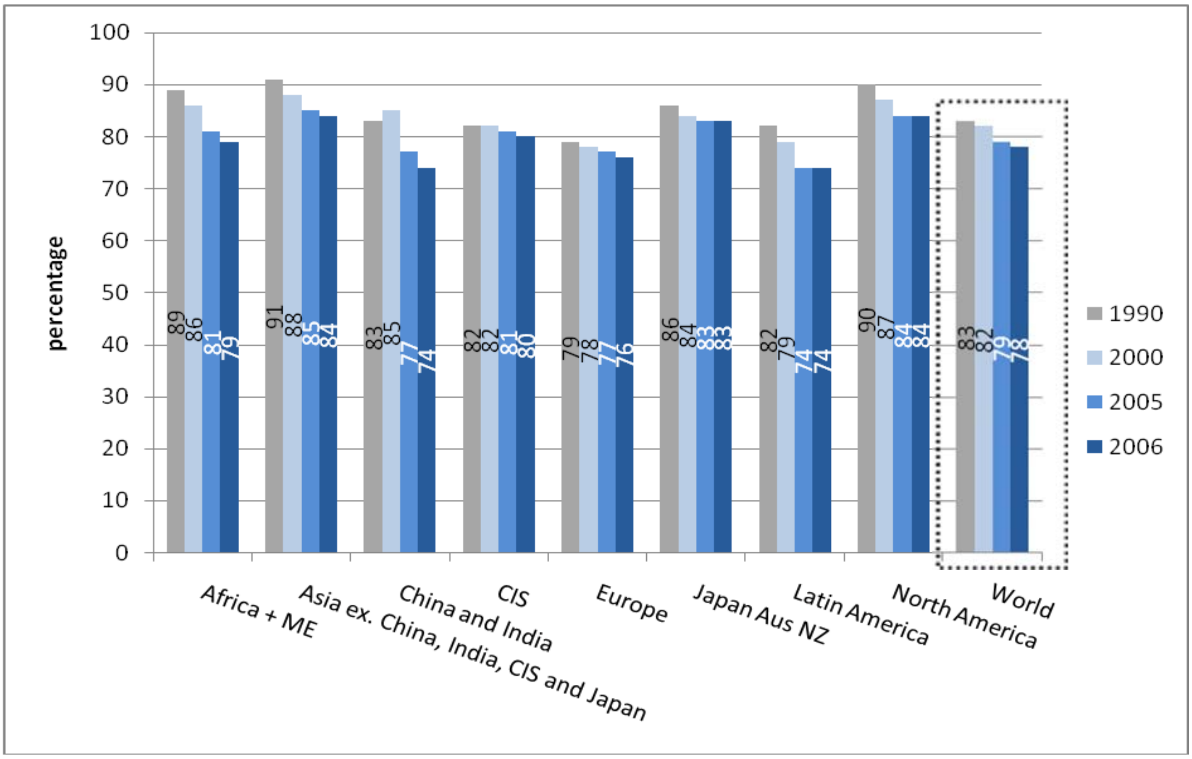

Figure 5.7: Clinker to cement ratio per region

From 2000 to 2006, the clinker to cement ratio decreased faster in non-Annex-I countries, overtaking Annex-I countries in performance. Several factors contribute to this. For example, whereas common practice and product standards are often a barrier to further reduce the clinker content, the procedures to change those may be more cumbersome in mature countries. In China and India particularly, the availability of fly ash from coal-fired power stations, slag from the iron and steel industry and pressure on the supply of primary energy, especially coal, can encourage wider use of clinker substitutes.

5.5 CO_2 emissions per tonne of cementitious

Net CO_2 emissions per tonne of cementitious product are shown for different regions in figure 5.8. Again, it is important to remember that the GNR provides good coverage of the Annex 1 region but less coverage for the non-Annex 1 region and thus for the world. Also, cementitious data is calculated at a consolidated country or company level, not at the individual plant level.

The performance in the Annex 1 regions is largely a result of the fairly high CO_2 intensity of the cement industry in North America, at 760 kg net and 790 kg gross CO_2 emissions per tonne of cementitious product, significantly higher than any other region.

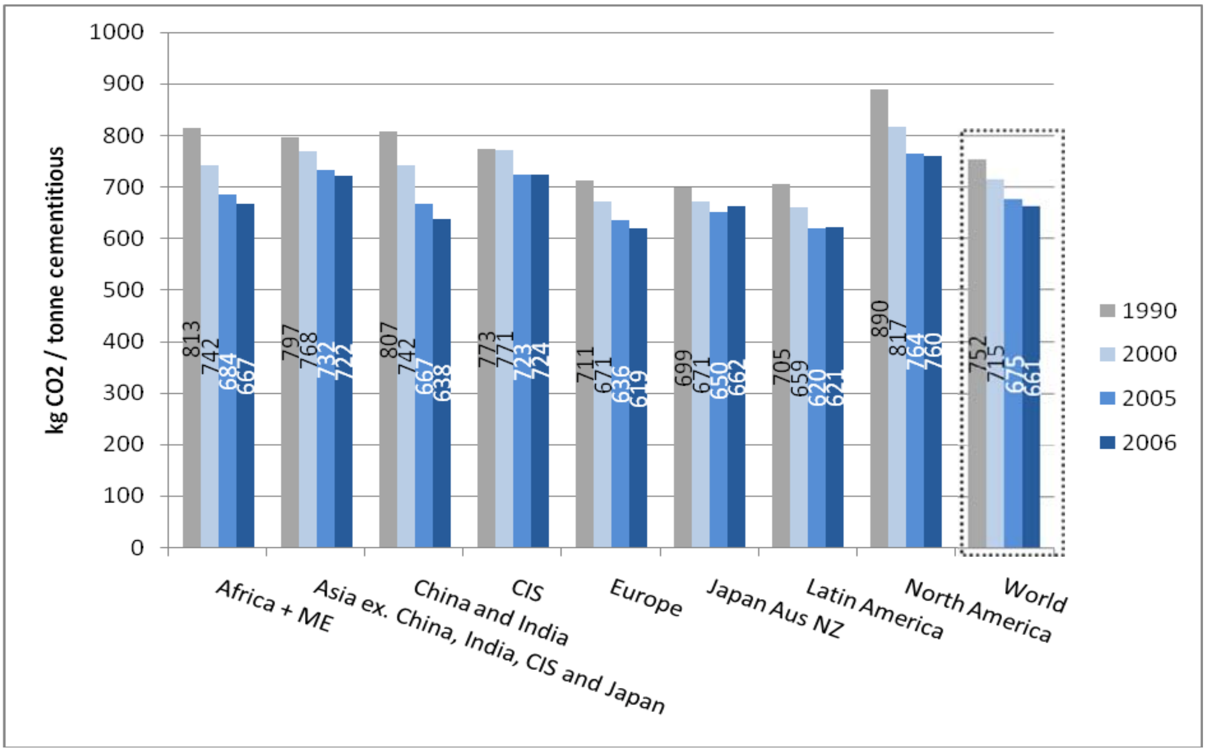

Figure 5.8: Regional average net CO_2 emissions per tonne cementitious

Average CO_2 emissions per tonne of cementitious product are lowest in Latin America, China and India, and Europe. The Japan-Australia-New Zealand region has seen little performance progress from 2000 to 2006 and is almost equal to the worldwide average.

Whereas CO_2 per tonne of clinker is better than the global average in Japan-Australia-New Zealand, Latin America and Africa-Middle East, overall net emissions per tonne of cement in Latin America and Europe are lower than the global average, whereas Japan-Australia-New Zealand and Africa-ME are nearer the average.

5.6 Specific electric energy consumption

Significant electrical energy is used in cement manufacturing (primarily for grinding) and is reported separately from kiln fuel use. Data on direct kiln emissions is thus not confused with data on emissions from a company's own power plants and indirect emissions from third-party power plants. Obviously, the thermal energy ultimately used when power is generated from kilns' waste heat is included in kiln fuel and emissions are included in direct kiln emissions.

GNR shows that, at a global level and in the Annex 1 region, specific electric energy consumption (kWh/tonne cement) has remained fairly constant from 2000 to 2006, whereas there is a ~5% improvement in the non-Annex 1 region. In the future it is hoped that GNR data will allow further studies of potential improvements in electric energy consumption.

5.7 Absolute CO_2 emissions

Despite a partial decoupling of CO_2 emissions and industry growth, absolute emissions have increased over time due to growing product demand. Figure 5.9 shows absolute gross CO_2 emissions volumes in Annex 1 and non-Annex 1 regions from 1990 to 2006.

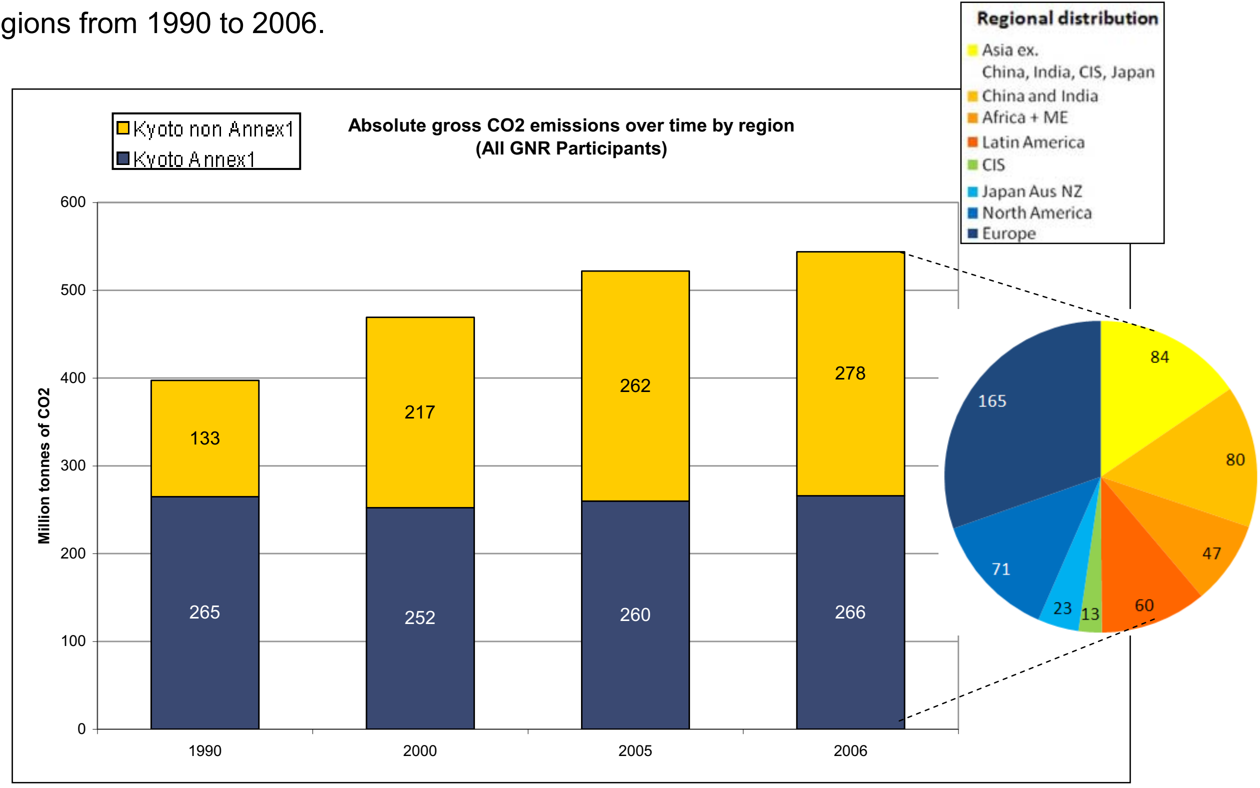

Figure 5.9: Absolute gross CO_2 emissions from 1990 to 2006

When comparing gross and net CO_2 emissions, the difference in emissions in 2006 was 14 million tonnes of CO_2 (gross emissions of 544 million tonnes and net of 530 million tonnes). This difference is due to the emissions from alternative fuels which are excluded from the net emission figures.

Direct emissions in the cement manufacturing process originate from two sources:

1) Decarbonization of limestone during clinker formation, a necessary process in cement manufacture
2) Burning of fuels to heat the materials in the clinker kiln to temperatures as high as 1,450ºC

Indirect emissions from electric power consumption contribute another 10% to overall CO_2 emissions.

Various levers can be used to reduce direct and indirect emissions and individual performance indicators can show trends over time (figure 5.11).

Lever for CO_2 emissions management	Performance indicator
Thermal efficiency per tonne of clinker	GJ per tonne of clinker
Technology and plant / kiln operations	Kiln type
Fuel mix	Fuel mix and thermal substitution of conventional fuels by alternative fuels and biomass
Clinker substitutes	Clinker to cement ratio
Indirect emissions from electric power used	Electric power per tonne cement
Emissions performance	Gross and net emissions per tonne of cementitious product

Figure 5.10: Levers and performance indicators for cement industry CO_2emissions

6 Performance analysis

6.1 Introduction to the statistical analyses

This chapter provides some analysis of the cement industry's performance and shows that the GNR database can give a solid basis for further research and analysis such as that carried out recently by IEA (2008)[8], WWF (2008)[9], McKinsey (2009)[10] and CSI (2009).[11]

A convenient tool for understanding the range of cement industry performance parameters is the cumulative frequency distribution curve (CFD). CFD curves show, for the total production volume in a given region, the value of the performance indicator (on the vertical axis), versus the percentage of the total production (on the horizontal axis) that has a performance better than or equal to the corresponding value on the vertical axis. These values are called percentiles. The tenth percentile, P10, corresponds to the "10% best in class". The fiftieth percentile, P50, is the median or the performance of 50% of the production in the region. Therefore, half perform better and half perform worse. The ninetieth percentile, P90 and above, corresponds to the "10% worst in the region", i.e., the highest energy use, highest emission, etc.

The average in the region is equal to the median if the frequency distribution is symmetrical. The average is higher than the median if the frequency distribution is asymmetrical, with relatively more product produced with a worse than average performance, and vice versa.

The slope of the CFD curve, i.e., the difference between the P10 and P90 data points, as well as the outliers, gives useful information on the range of performance for a given variable. A low slope, i.e., a nearly flat line, shows that most kilns are performing at a similar level.

The analyses below refer to grey clinker and cement only, the dominant industry product.

Many of the following CFDs reveal a remarkable linearity between the ~10th and ~90th percentiles, indicating fairly widespread "normal" practice throughout the industry. The curves below the 10th percentile and above the 90th percentile deviate from the linear curve, indicating "outliers" or "special conditions". These special conditions include factors such as exceptionally good or poor regional availability of biomass or clinker substitution materials, or an extraordinarily wet limestone raw material. The special conditions of the outliers can rarely be extrapolated to the bulk of the production. The outliers, being few in number, have a limited impact on the overall statistical performance of the industry.

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[8] *Energy Technology Perspectives 2008*, International Energy Agency (IEA) (2008).

[9] *A Blueprint for the Cement Industry: How to Turn Around the Trend of Cement Related Emissions in the Developing World*, WWF (December 2008).

[10] Version 2 of the *Global Greenhouse Gas Abatement Cost Curve*, McKinsey (January 2009).

[11] "A Sectoral Approach to GhG Mitigation in the Cement Industry", CSI presentation at UNFCCC, Bonn, Germany (June, 2009). See www.wbcsdcement.org/sectoral

6.2 Thermal energy efficiency of clinker production

Figure 6.1 shows the cumulative frequency distributions of the thermal energy consumption in clinker installations globally. There is also an indication of the average performance of different kiln types, from section 5.1. The CFD shows a linear curve from around the 5th to 85th percentiles. Very few installations perform better than 3,000 MJ/t clinker, however this is only feasible with extremely dry raw materials that are the exception rather than the rule. About 15% of production in wet and semi-wet process installations consume more than 4,000 MJ/t clinker. (Note: vertical shaft kilns are excluded due to insufficient performance information available from GNR participants who operate very few of this kiln type).

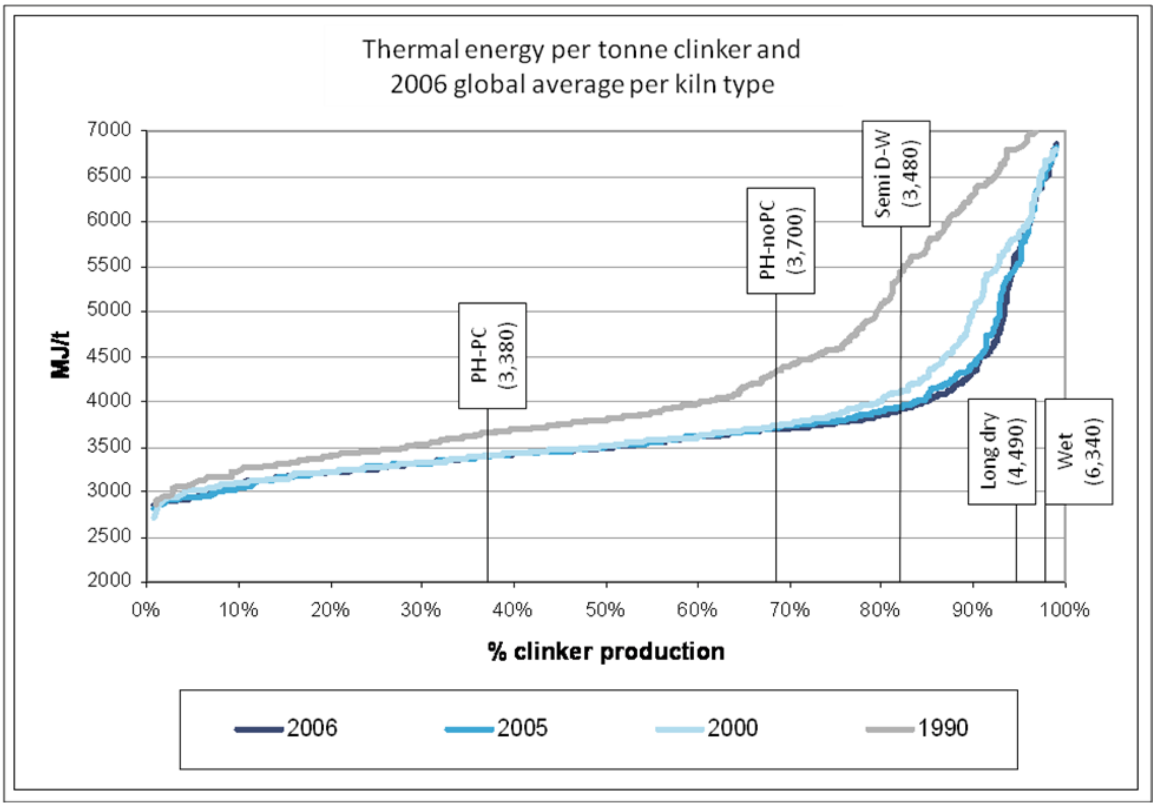


Figure 6.1 Thermal energy consumption per tonne of clinker & global average per kiln type 2006

Energy intensive installations are most common in the Commonwealth of Independent States (CIS), with more than 80% of production in wet and semi-wet process installations, and North America, where around 40% of production consumes more than 4,000 MJ/t clinker. CSI companies' wet process operations are least common in Japan-Australia-NZ, Asia and Latin America, with 5% or less of production consuming above 4,000 MJ/t clinker. Wet and semi-wet process installations account for around 10% of production in the EU.

It is noteworthy that only very few individual clinker installations perform at close to 3,000 MJ/t clinker, mainly in Japan. The 20% best-in-class corresponds to a performance of 3,200 MJ/t clinker. This reflects the technical limits of thermal efficiency in day-to-day routine operations with current technology. The best performance achieved by a GNR installation was around 2,900 MJ/t clinker.

Thermal efficiencies shown in Figure 6.1 reflect the changing mix of kiln types across the global cement industry as older, inefficient kilns (wet, semi-wet/semi-dry) are being retired while new, more efficient (preheater-precalciner) kilns are built in developing economies to meet local demand. Efficiencies for individual kiln technologies have not changed substantially.

6.3 Sourcing energy from alternative fossil fuels and biomass

The CFDs in Figure 6.2 below further highlight the wide variations in alternative fuel use around the world.

While in 1990 85% of clinker production did not use alternative fossil fuels, in 2006, about 50% of global clinker production did use some alternative fossil fuel. Alternative fuel use among GNR participants rose from 15% of global clinker production in 1990 to 50% in 2006. About 5% of clinker production sourced more than 50% of the energy needs from alternative fossil fuels. The use of biomass is, so far, less developed in the cement industry, with only 30% of production using some biomass in 2006, at levels of up to a maximum of 30% of the installation's energy mix (see Figure 6.3).

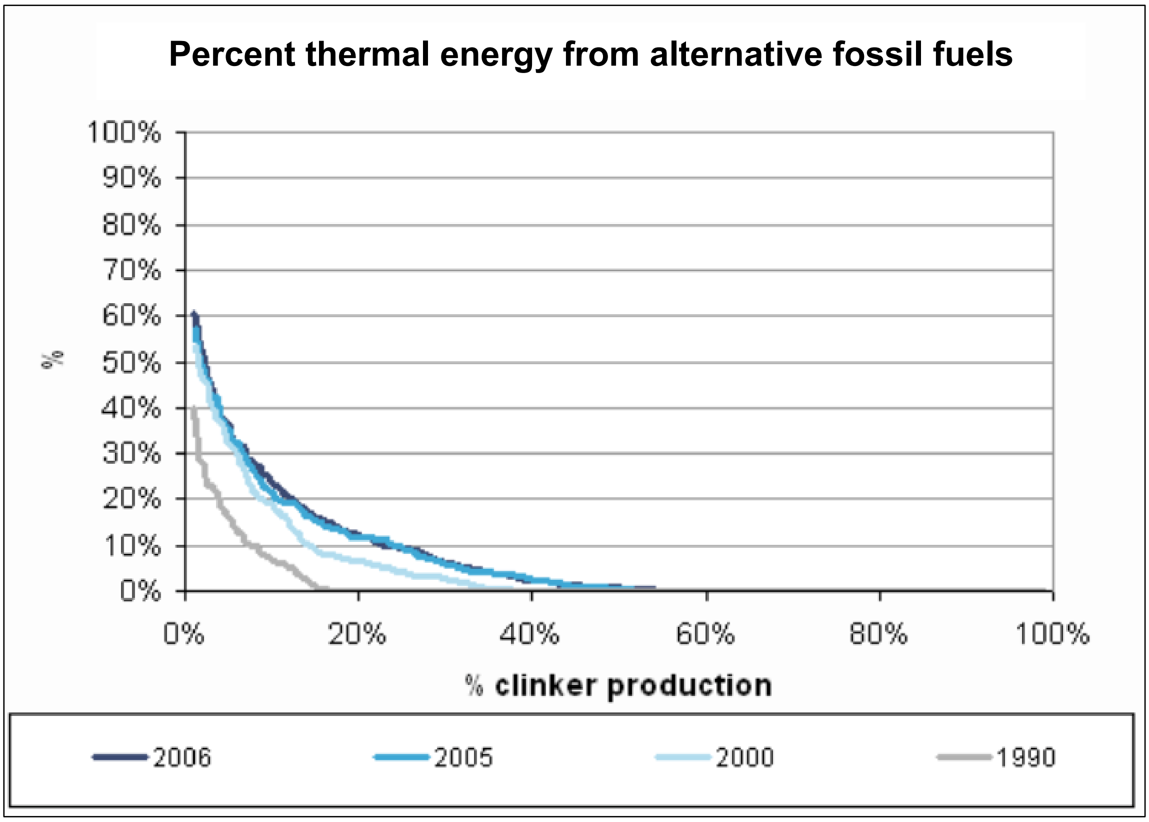


Figure 6.2: Percent thermal energy from alternative fossil fuels amongst GNR participants

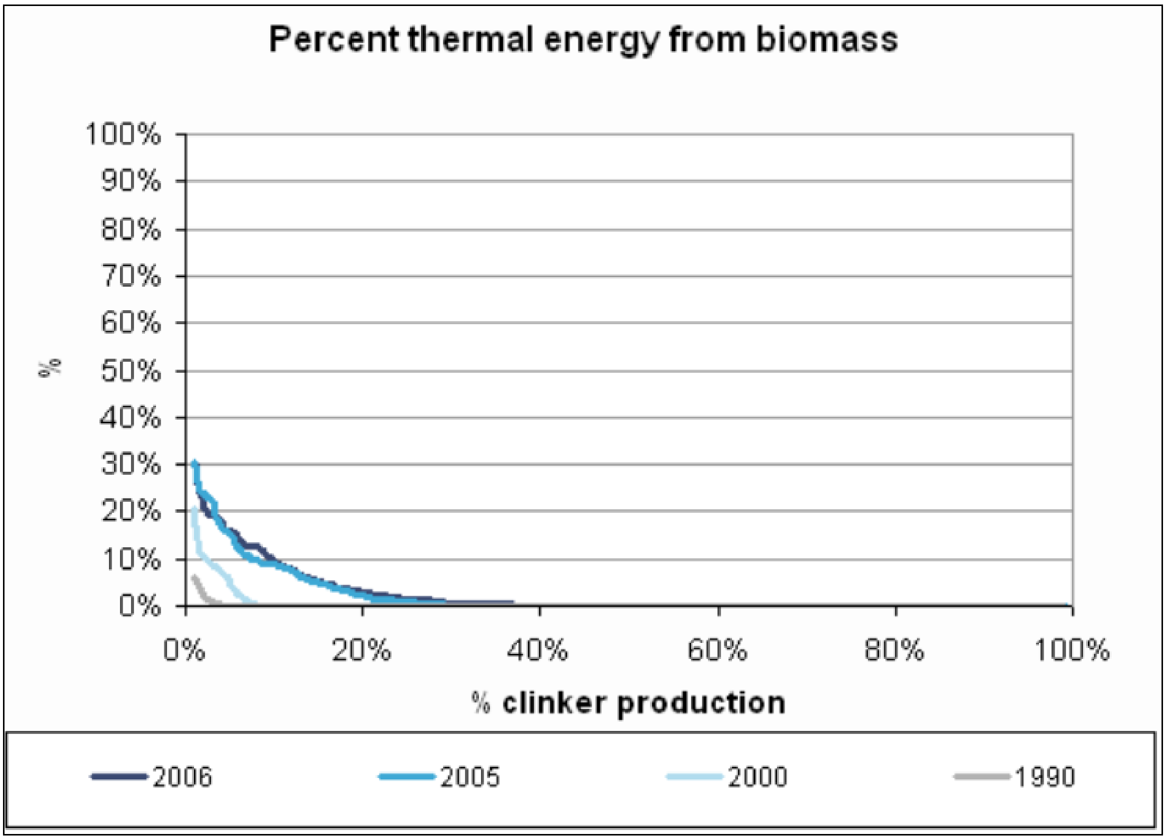


Figure 6.3 Percent thermal energy from biomass

Statistics available in GNR for all regions also highlight important regional differences in alternative fuel use. In Europe, with well-developed environmental legislation, waste management systems, and law enforcement, up to 70% of clinker production installations source energy from alternative fuels. Some installations source up to around 65% of energy from fossil waste. Up to 45% of installations source energy from biomass although this is in smaller quantities. Regarding the substitution of solid fossil fuels by biomass, cement companies can use biomass equally effectively as, for example, electric power utilities.

It is noteworthy that up to 80% of clinker production in Japan-Oceania uses alternative fossil fuel as a source of energy but only up to around 20% thermal substitution rate.

In North America, 60% of clinker production uses alternative fossil fuel, for up to a maximum of 40% of energy, but very little biomass. In Latin America around 80% of production uses alternative fossil fuel and biomass; some installations use over 30% energy from biomass.

There is significant potential to further develop the sourcing of thermal energy from alternative fossil fuel, especially waste, and biomass across all regions of the world.

Such development, however, largely depends on governmental policies such as the development, control and enforcement of waste legislation and the subsequent development of waste collection and pre-treatment infrastructure by public or private companies. CO_2 reduction credits for the resulting prevention of greenhouse gas emissions at the waste disposal sites could provide important incentives for these developments

6.4 Gross CO_2 emissions per tonne of clinker

Figure 6.4 shows cumulative frequency distributions (CFDs) of global gross CO_2 emissions per tonne of clinker (2006).

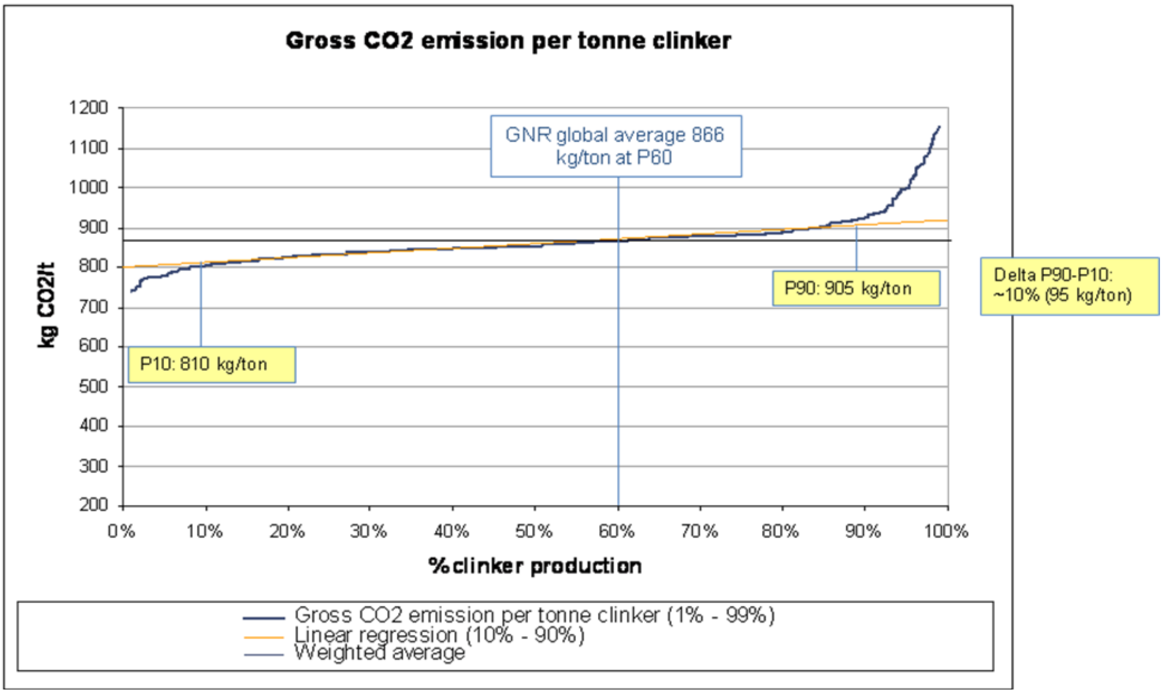


Figure 6.4: Gross CO_2 emissions per tonne of clinker, 2006

Whereas one might expect similarity between the statistics of gross CO_2 emissions per tonne of clinker and of thermal consumption, they are in fact quite different. The CFDs of CO_2 per tonne of clinker are generally much flatter than those of thermal consumption, revealing a smaller difference between the best and the worst performers.

This small differentiation in gross CO_2 emissions per tonne of clinker, compared to the large spread in thermal consumption, is a consequence of two factors:

(1) about 60% of gross CO_2 emissions originate fom limestone decomposition

(2) 40% are fuel emissions where, apart from energy efficiency, the fuel composition plays a role. For example, highly energy intensive installations in the CIS largely use natural gas, whereas more energy-efficient installations in Asia mainly use coal.

As a result, the tail of CO_2 intensive installations (the upper end of the CFD curve) is relatively smaller than the tail of energy-intensive installations, whereas the tail of exceptionally well-performing installations (the lower end of the CFD curve) is slightly larger because some energy efficient installations also use lower CO_2 intensive fuels (e.g., alternative fossil fuels and biomass fuels).

The spread between the 10th and 90th percentiles is 11% at a global level and 9.5% or less in Europe and Asia.

While there is room for improvement for some individual CO_2-intensive installations, the potential for further improvement of global CO_2 emissions per tonne of clinker with current technology and traditional fuels is quite small. For example improving average performance by 10% globally would require all current GNR participants to reach nearly best in class. Even upgrading 90% of the CSI's global clinker installations to the level of the top 10% performers would only lead to around a 6.5% reduction of total CO_2 emissions. Consequently, replacing all wet and semi-wet installations with best technology would result in only 9 million tonnes or a 1.7% reduction in emissions per year, at an roughly estimated capital cost of €5-10 billion, depending on whether they are newly built or reused. As discussed earlier, wet and semi-wet processes consume more energy because they need to remove a good deal of water from the limestone feed. But many wet kilns are located in CIS countries where natural gas, a low-carbon fuel, is widely used. The proportion of production in CO_2-intensive installations has significantly decreased over the 16 years, but the CO_2 efficiency of the best performers has only slightly improved. This is once more an indication of the limited potential to further improve CO_2 efficiency per tonne of clinker with current technology.

6.5 Clinker substitution

Sections 5.4 and 5.5 already illustrate the importance of clinker substitution for CO_2 emissions reductions. Figure 6.5, showing the statistics of the clinker to cement ratio globally, illustrates the large variation of this practice across national companies.

Globally, companies sell cements comprising clinker and mineral components. In some countries, when mineral components are available, companies sell these components directly to the construction sector. When clinker used in cement production is expressed as a percentage of the total company sales (including direct sales of mineral components), 13% of companies achieve an index less than 70%. This index does not, however, reflect the percentage of clinker in blended cements comprising clinker and mineral components. As a corporate aggregate figure, this index is not available at plant level.

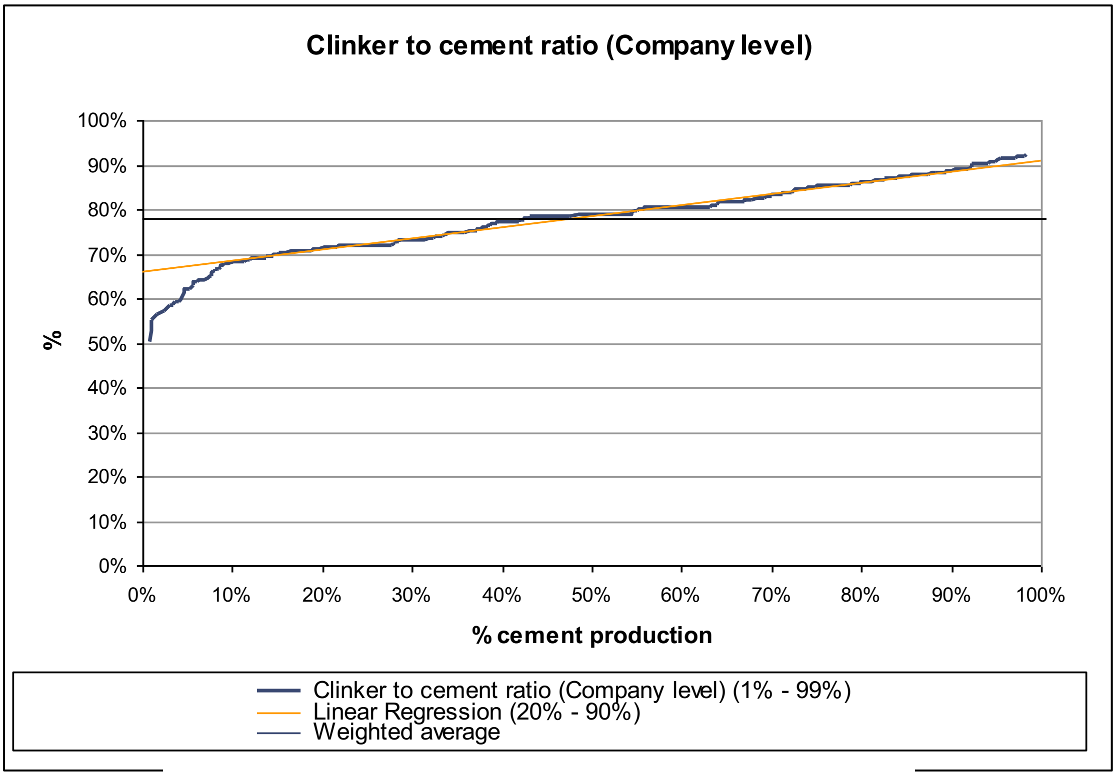


Figure 6.5: Clinker to cement ratio globally

6.6 CO_2 emissions per tonne of cementitious

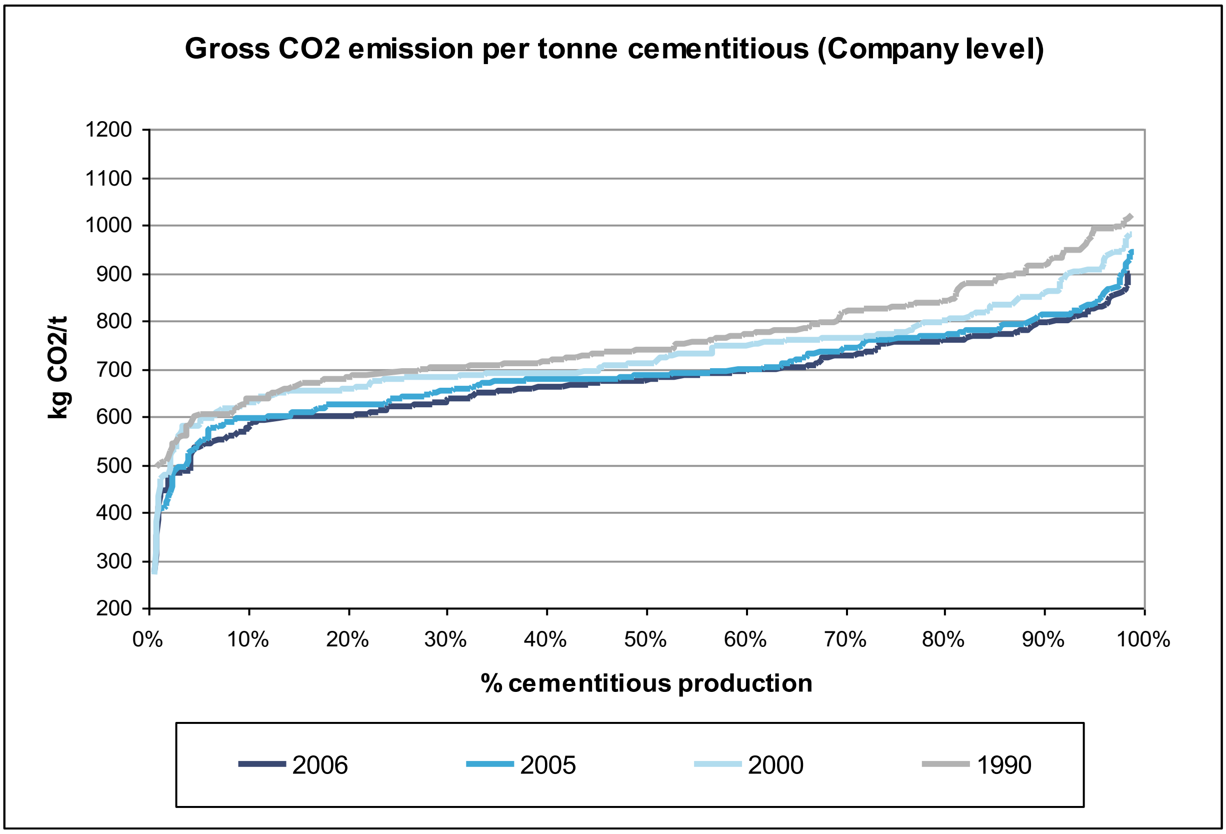


Figure 6.6: Gross CO_2 emissions per tonne cementitious

Figure 6.6 shows the CFD of gross CO_2 emissions per tonne of cementitious product over the four reporting years. The best performing companies, below 500, are generally companies trading cementitious products independent of clinker production. In accordance with the CO_2 Protocol, a reduction in the ratio is allowed because the amount delivered to final customers is included in the definition of cementitious.

There is again a strong linear correlation in performance between the 10th and 90th percentiles. Although not illustrated in this curve, the regional differentiation is large: CO_2 intensity per tonne cementitious product is systematically 12% higher in North America compared to globally and 9% and 6% lower respectively in Latin America and Europe. While the Asian average is almost 10% above the global average, the slope of the Asian curve is twice as steep as the global curve, showing a large spread in CO_2 emissions per tonne cementitious product performance in Asia.

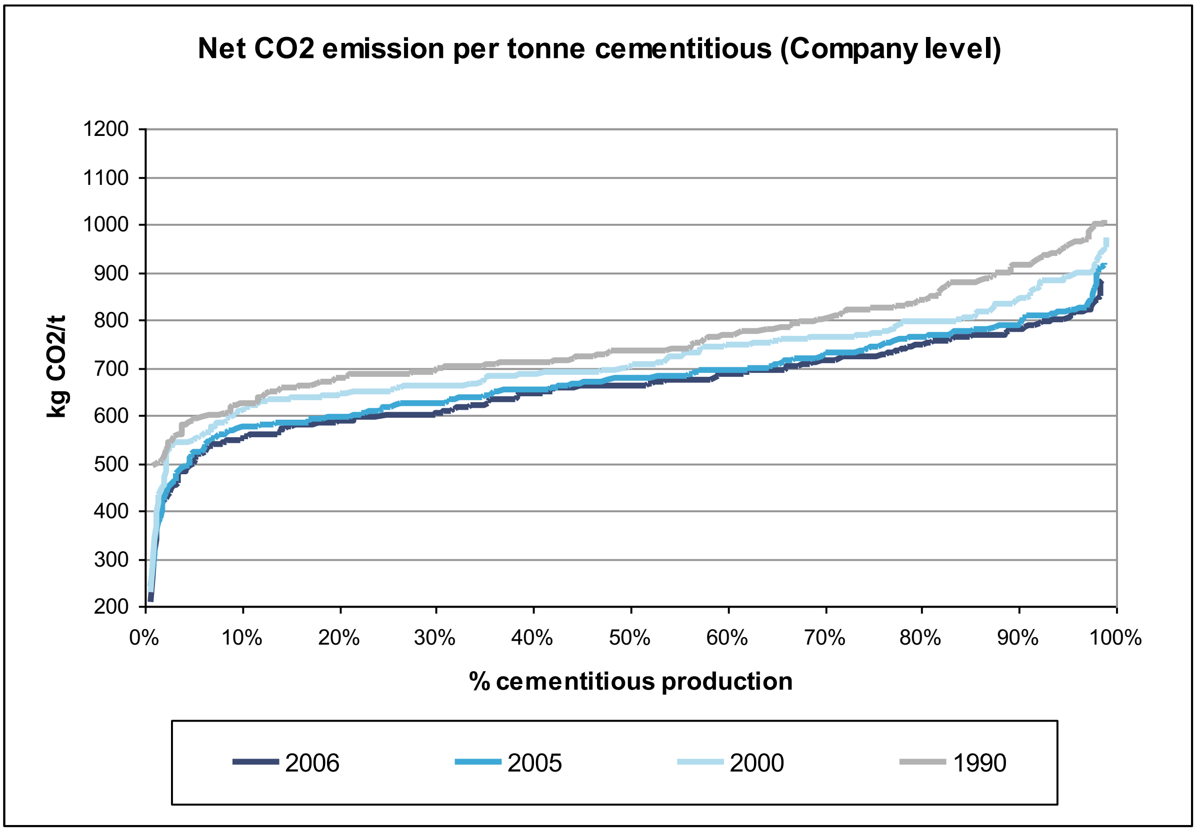


Figure 6.7: Net CO_2 emissions per tonne cementitious

Figure 6.7 shows net CO_2 emissions per tonne of cementitious. Clinker substitution affects the technical characteristics of cement. Not all applications require “high clinker content” ordinary Portland cement (OPC). Reducing the clinker content in cement and thus reducing CO_2 emissions per tonne of cementitious is part of adapting the qualities of the cement to the requirements of the application. Usually cements are defined in standards by their performance characteristics (an exception being in the US where composition is used). More and more cement standards allow a wide range of constituents provided performance requirements are met, but there are still markets where cement and concrete standards and customer preference constitute a barrier to reducing the clinker-to-cement ratio, and hence reducing CO_2 emissions.

7 Data queries

Stakeholder engagement is a key feature of WBCSD programs, and that holds true for the GNR database in two ways.

First, stakeholders had a key role in the development, review and revision of the WBCSD/CSI CO_2 reporting protocol. Revisions were made in the 2nd edition (December 2005) based on stakeholder feedback, including comments from the World Resources Institute, KPMG and the US Environmental Protection Agency.

Second, the CSI has set up a process for handling requests for GNR database information via a Project Management Committee (PMC), which serves as a link between PwC and the participating companies. 30 such requests were dealt with in 2008. Those interested in making queries of the database should send requests directly to:

gnrpmc@wbcsd.org

The request should indicate the following information:

1. Name and function of the requesting organization
2. A description of the proposed use of the data
3. Contact details for responses or further clarification
4. Details of the requested information
5. Geographic coverage
6. Specific variables requested
7. Time frame for data

The PMC will review all requests to determine, first, if the data is available, and second, if responses to the query would fall within the limits of confidentiality and anti-trust constraints adopted for this program. These constraints will limit our ability to respond to every request for data (e.g., requests for single country data).

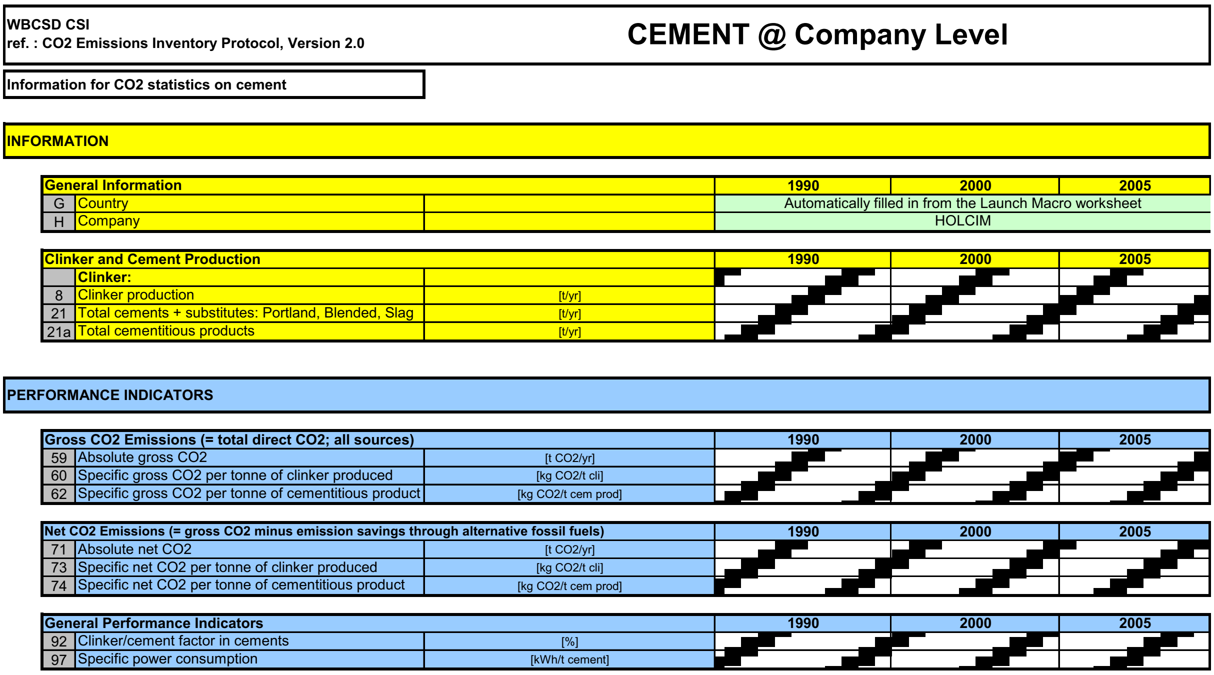
Approved requests are forwarded to PwC for processing and a final check for compliance with antitrust and confidentiality rules. Assuming that no legal issues are raised by the query, PwC will perform the database query and return the results to the PMC, which will in turn respond to the originator of the query.

The CSI may carry some or all of the costs associated with “reasonable” requests from public institutions. For other organizations or for complex requests there may be a charge levied to cover the costs for the work. In such cases the query originator will be informed about the expected charge and payment terms prior to commencing the analysis.

8 Annexes

8.1 Data collection

Information requested at company level



WBCSD CSI
ref. : CO2 Emissions Inventory Protocol, Version 2.0

CEMENT @ Company Level

Information for CO2 statistics on cement

INFORMATION

General Information			**1990**	**2000**	**2005**
G	Country		Automatically filled in from the Launch Macro worksheet		
H	Company		HOLCIM		

Clinker and Cement Production			**1990**	**2000**	**2005**
	Clinker:				
8	Clinker production	[t/yr]	▨	▨	▨
21	Total cements + substitutes: Portland, Blended, Slag	[t/yr]	▨	▨	▨
21a	Total cementitious products	[t/yr]	▨	▨	▨

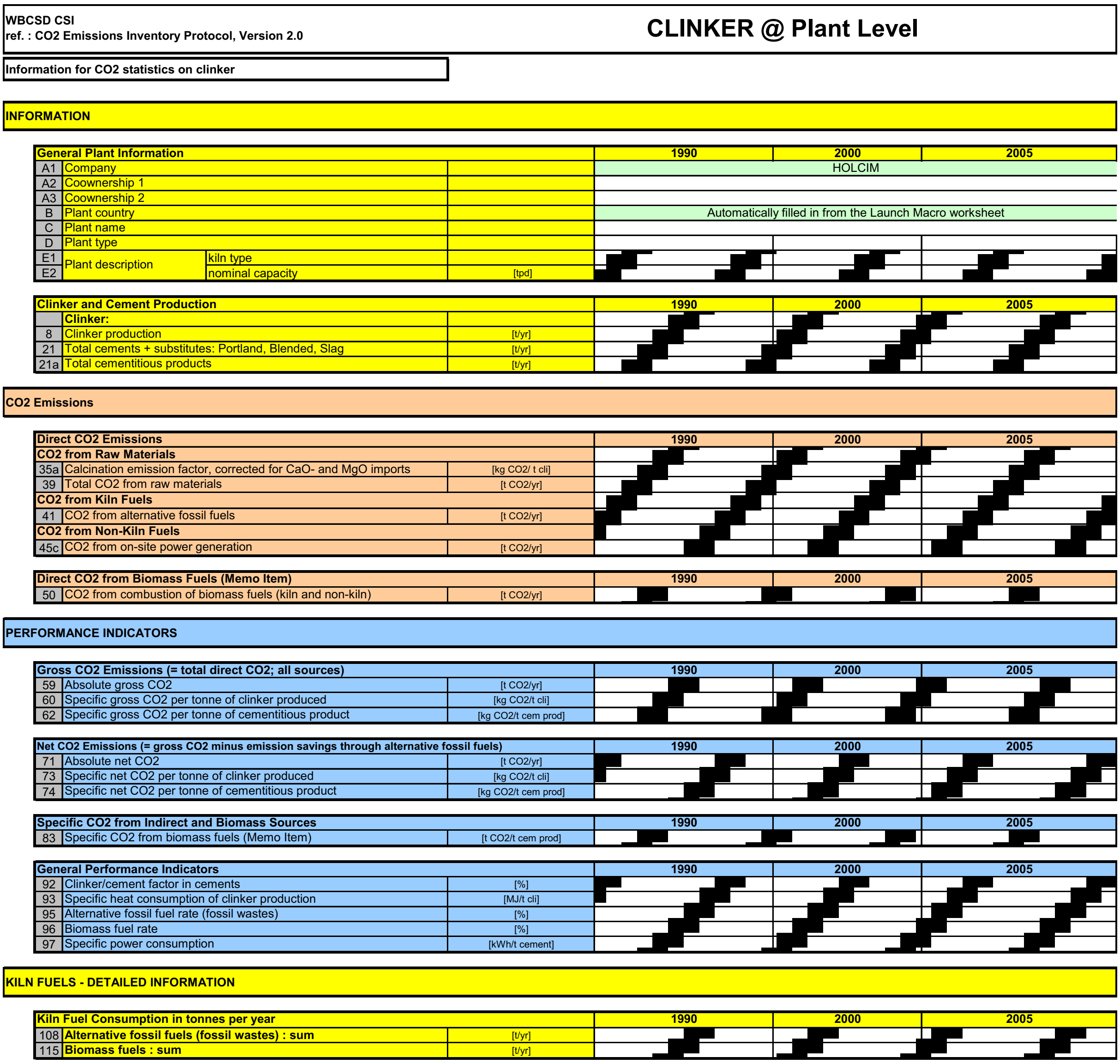
PERFORMANCE INDICATORS

Gross CO2 Emissions (= total direct CO2; all sources)			**1990**	**2000**	**2005**
59	Absolute gross CO2	[t CO2/yr]	▨	▨	▨
60	Specific gross CO2 per tonne of clinker produced	[kg CO2/t cli]	▨	▨	▨
62	Specific gross CO2 per tonne of cementitious product	[kg CO2/t cem prod]	▨	▨	▨

Net CO2 Emissions (= gross CO2 minus emission savings through alternative fossil fuels)			**1990**	**2000**	**2005**
71	Absolute net CO2	[t CO2/yr]	▨	▨	▨
73	Specific net CO2 per tonne of clinker produced	[kg CO2/t cli]	▨	▨	▨
74	Specific net CO2 per tonne of cementitious product	[kg CO2/t cem prod]	▨	▨	▨

General Performance Indicators			**1990**	**2000**	**2005**
92	Clinker/cement factor in cements	[%]	▨	▨	▨
97	Specific power consumption	[kWh/t cement]	▨	▨	▨

Information requested at site level



WBCSD CSI
ref. : CO2 Emissions Inventory Protocol, Version 2.0

CLINKER @ Plant Level

Information for CO2 statistics on clinker

INFORMATION

	General Plant Information			**1990**	**2000**	**2005**
A1	Company			HOLCIM		
A2	Coownership 1					
A3	Coownership 2					
B	Plant country			Automatically filled in from the Launch Macro worksheet		
C	Plant name					
D	Plant type					
E1	Plant description	kiln type				
E2		nominal capacity	[tpd]			

	Clinker and Cement Production		**1990**	**2000**	**2005**
	Clinker:				
8	Clinker production	[t/yr]			
21	Total cements + substitutes: Portland, Blended, Slag	[t/yr]			
21a	Total cementitious products	[t/yr]			

CO2 Emissions

	Direct CO2 Emissions		**1990**	**2000**	**2005**
	CO2 from Raw Materials				
35a	Calcination emission factor, corrected for CaO- and MgO imports	[kg CO2/ t cli]			
39	Total CO2 from raw materials	[t CO2/yr]			
	CO2 from Kiln Fuels				
41	CO2 from alternative fossil fuels	[t CO2/yr]			
	CO2 from Non-Kiln Fuels				
45c	CO2 from on-site power generation	[t CO2/yr]			

	Direct CO2 from Biomass Fuels (Memo Item)		**1990**	**2000**	**2005**
50	CO2 from combustion of biomass fuels (kiln and non-kiln)	[t CO2/yr]			

PERFORMANCE INDICATORS

	Gross CO2 Emissions (= total direct CO2; all sources)		**1990**	**2000**	**2005**
59	Absolute gross CO2	[t CO2/yr]			
60	Specific gross CO2 per tonne of clinker produced	[kg CO2/t cli]			
62	Specific gross CO2 per tonne of cementitious product	[kg CO2/t cem prod]			

	Net CO2 Emissions (= gross CO2 minus emission savings through alternative fossil fuels)		**1990**	**2000**	**2005**
71	Absolute net CO2	[t CO2/yr]			
73	Specific net CO2 per tonne of clinker produced	[kg CO2/t cli]			
74	Specific net CO2 per tonne of cementitious product	[kg CO2/t cem prod]			

	Specific CO2 from Indirect and Biomass Sources		**1990**	**2000**	**2005**
83	Specific CO2 from biomass fuels (Memo Item)	[t CO2/t cem prod]			

	General Performance Indicators		**1990**	**2000**	**2005**
92	Clinker/cement factor in cements	[%]			
93	Specific heat consumption of clinker production	[MJ/t cli]			
95	Alternative fossil fuel rate (fossil wastes)	[%]			
96	Biomass fuel rate	[%]			
97	Specific power consumption	[kWh/t cement]			

KILN FUELS - DETAILED INFORMATION

	Kiln Fuel Consumption in tonnes per year		**1990**	**2000**	**2005**
108	**Alternative fossil fuels (fossil wastes) : sum**	[t/yr]			
115	**Biomass fuels : sum**	[t/yr]			

8.2 *Production process and technology*

CEMENT PRODUCTION

a. What is cement?

Cement is a hydraulic powder material, which reacts with water to produce strength-bearing lattices. The mixture of aggregates, cement and water is concrete. The strength and durability of concrete makes it one of the most useful materials developed by man. The chemistry and mineralogy of cement is complex. In simple terms, cement is a manmade mineral structure created at high temperatures, mainly comprising lime (CaO), Silica (SiO_2) and oxides of aluminum and iron (Al_2O_3 and Fe_2O_3).

The cement-making process can be divided into two basic steps; first “clinker” is made at temperatures of 1,400 ^{0}C. Then the clinker is milled with other minerals to produce the powder we know as cement.

b. Raw materials

The raw materials, used to produce clinker include some naturally occurring minerals and some materials available as waste streams from other industries. The most common combination of ingredients is limestone (for calcium) coupled with much smaller quantities of clay, shale and sand (as a source of silica, aluminum and iron). Other “alternative” raw materials, such as mill scale, fly ash and slag, are brought in from other industries. Plants generally rely on nearby quarries for limestone to minimize transport.

Rock blasted from the quarry face is transported to the primary crusher where large “run of mine” rocks are broken into pieces of approximately 100 mm. Generally the other raw materials do not require crushing. The raw materials are then proportioned to the correct chemical balance and milled together to a fine powder, “raw meal”. To ensure a high quality of cement, the chemistry of the raw materials and raw meal is very carefully controlled. Kiln exhaust gases are used in the raw mill to dry the raw materials. In some cases with wet materials, additional heat sources are required for drying. Materials are also homogenized to ensure consistency of product quality.

c. Preheater

Raw meal is the feed material for the high-temperature process in the kiln system. “Preheating” is the first part of this system. A preheater is a series of vertical cyclones. As the raw meal is passed down through these cyclones it comes into contact with the swirling hot kiln exhaust gases moving in the opposite direction and as a result heat is transferred from the gas to material. This preheats the material before it enters the kiln so that the necessary chemical reactions will occur more quickly and efficiently. By retaining energy from the exhaust gases, energy is saved. Depending on the raw material moisture, a kiln may have 3 to 6 stages of cyclones with increasing heat recovery with each extra stage.

The calciner is a combustion chamber at the bottom of the preheater above the kiln back-end. Up to 65% of the total energy needs of the kiln system can be supplied to the calciner. Calciners allow for shorter rotary kilns and for the use of lower grade alternative fuels. Calcination is the decomposition of $CaCO_3$ to CaO, which releases CO_2. These process emissions comprise approximately 60% of the total emissions from a cement kiln. The combustion of the fuel generates the rest.

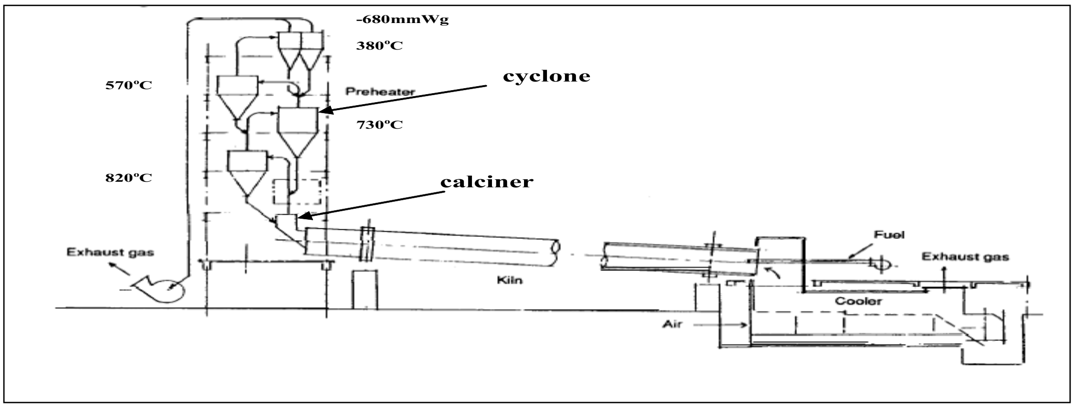


Figure 8.1: Schematic diagram kiln

d. Kiln

Raw meal, more accurately termed “hot meal” at this stage then enters the rotary kiln. The kiln is the world’s largest piece of industrial equipment. Fuel is fired directly into the rotary kiln and ash, as with the calciner, is absorbed into the material being processed. As the kiln rotates about 3-5 times per minute, the material slides and tumbles down through progressively hotter zones towards the flame. Coal, pet coke, natural gas and, increasingly alternative fuels such as plastic, solvents, waste oil or meat and bone meal are burned to feed the flame, which can reach as high as 2,000^{0}C. This allows the materials to become partially molten as the intense heat causes the chemical and physical changes that transform the raw feedstock into a material called clinker. Expressed at its simplest, the series of chemical reactions converts the calcium and silicon oxides into calcium silicates, cement primary constituent.

e. Technology

There are two basic types of cement production processes and a number of different kiln types. Cement production is either “wet” or “dry”, depending on the water content of the material feedstock. The wet process was the original rotary kiln process developed at a time when material handling of slurries was more developed than those of dry powders. It is still being used to process very wet raw materials and allows for easier control of the chemistry. However, it has much higher energy requirements due to the amount of slurry water that must be evaporated before calcinations can take place. The dry process avoids the use of slurry material and as a result is far less energy intensive. Modern day kilns are much more efficient than the kilns of old.

f. Cooling/finished grinding

The clinker tumbles onto a grate cooled by forced air. Once cooled the clinker is ready to be ground into the grey powder known as Portland cement. To save energy, heat recovered from this cooling process is re-circulated back to the kiln or preheater tower.

The clinker is ground with other mineral components to Portland or blended cement. Gypsum is used to control the setting time of the product; slag, fly ash, limestone and gypsum can also be used to control other properties of the cement. The use of these materials reduces the total carbon footprint of the cement. Mineral components can be used at different production stages (cement and concrete) depending on the local product standards, common practices and market situations. In some countries, they are traditionally used at the concrete manufacturing plant with high clinker content cement supplied by the cement plant. Traditionally, ball mills have been used for cement milling. In recent years technologies with better energy efficiency have been developed. Compound mill systems include pre-crushing and sophisticated separator systems to reduce electricity consumption. Vertical cement mills mill the material in a roller mill with reduced electricity consumption.

From the grinding mills, the cement is conveyed to silos for shipment. Most cement is shipped in bulk by truck, rail or barge. A small percentage of the cement is bagged for customers who need only small amounts.

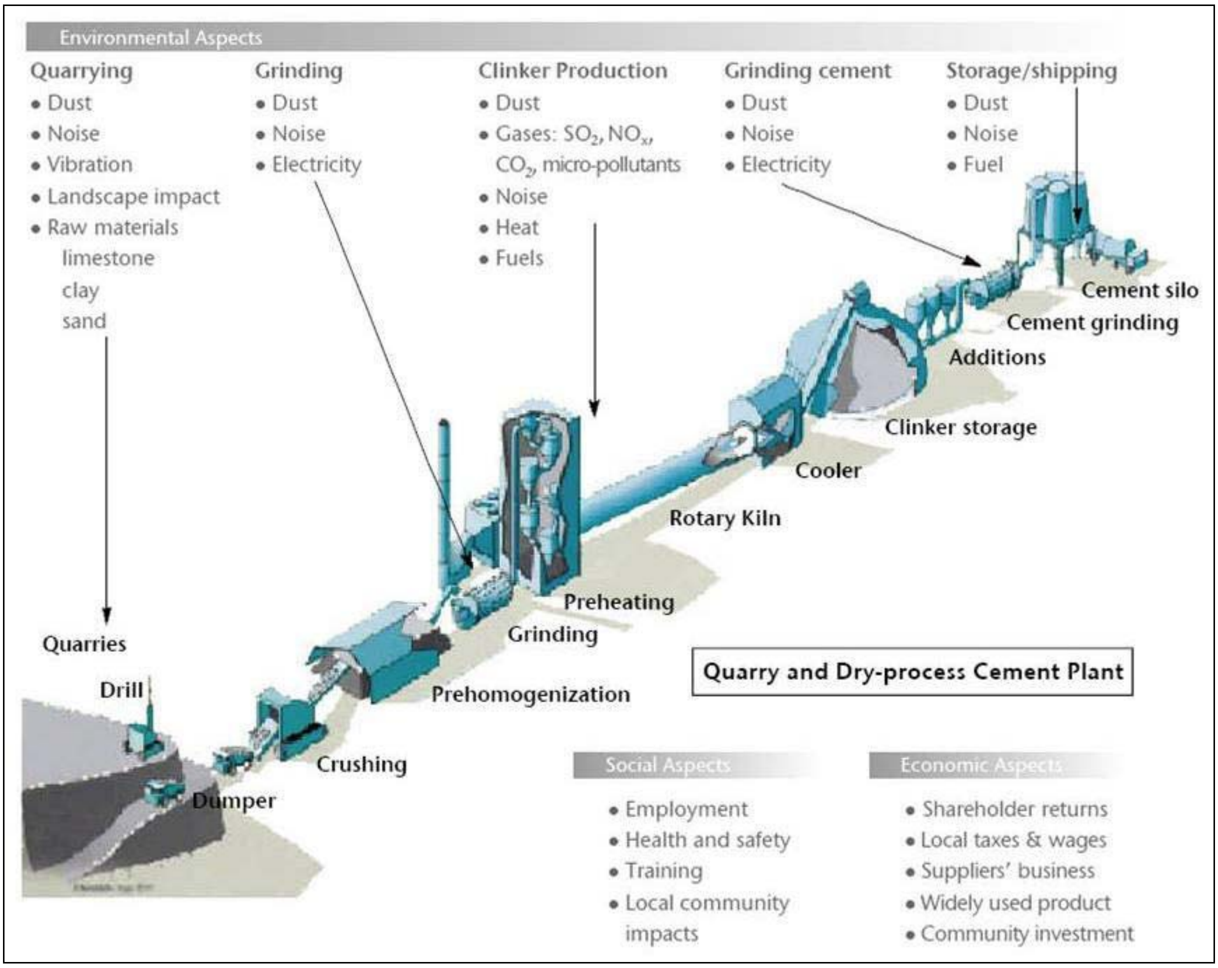


Figure 8.2: Quarry and dry-process cement plant

Cement production as an ecosystem

Many industrial byproducts and other waste materials can be recovered and used in cement manufacture. Some are incorporated into the cement, others provide fuel needed to convert limestone into cement. This diagram illustrates some of the materials being used by companies around the world. Not all of them are used in every country. Some are actively encouraged in some countries, but prohibited in others. For example, used tires are routinely burned as fuel in cement plants in Japan, France, and Germany. But this practice is controversial in several other countries. See page 22 for more details about the Cement Sustainability Initiative's work on alternative fuels and raw materials.

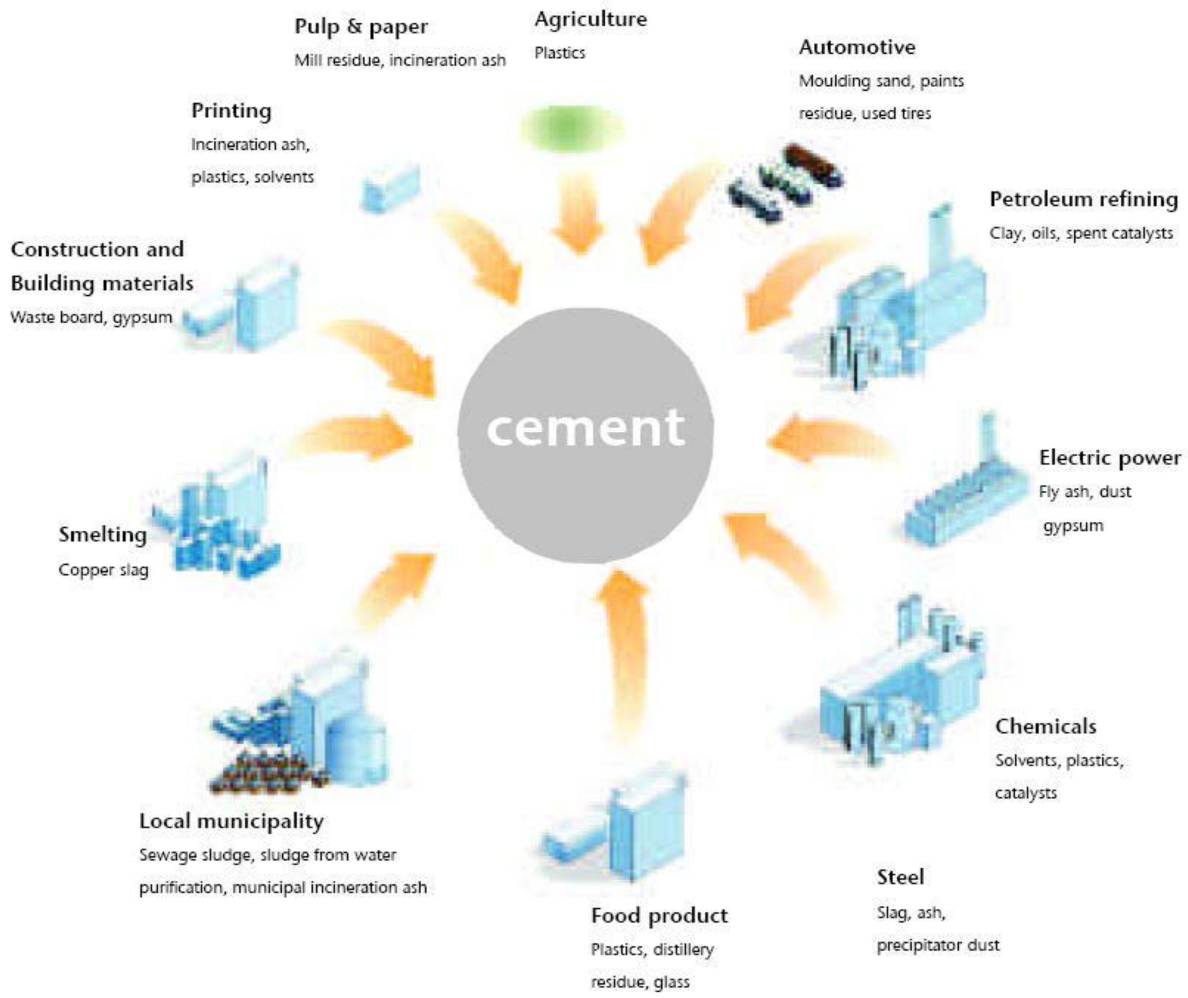


Figure 8.3: Cement production as an ecosystem[12]

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[12] Taken from ***The Cement Sustainability Initiative, Our Agenda for Action***, p. 11, WBCSD, 2002, Geneva.

8.3 Glossary

- **Alternative fossil fuels**: Products from fossil origin used as a source of thermal energy and not classified as traditional fossil fuel. This is mainly fossil waste such as plastics, solvents, waste oil, end-of-life tires etc.
- **ASTM** : American Society for Testing and Materials
- **Biomass**: Products from biogenic origin used as a source of thermal energy, including from animal or plant origin. This is mainly waste from agriculture, forestry, biologic waste water treatment and agro-industry.
- **Cement**: The finished product of the cement plant delivered to the customer, obtained by grinding clinker together with various mineral components such as gypsum, limestone, blast furnace slag, coal fly ash and natural volcanic material. While cement qualities are defined by national standards (such as the European CEN and American ASTM standards), there is no worldwide harmonized definition or standard of cement. In the WBCSD – CSI Protocol and the GNR database,“cement” includes all hydraulic binders that are delivered to the final customer, i.e., including all types of Portland, composite and blended cements plus ground granulated slag and fly ash delivered to the concrete mixers, but excluding clinker. The precise definition of cement in this context is according to section 6.3 of the WBCSD – CSI Cement Protocol.
- **Cementitious products**: Total of all cements and clinker produced by a cement company, excluding the clinker purchased from another company and used to make cement. The precise definition of cementitious product in this context is according to section 6.2 of the WBCSD – CSI Cement Protocol. Cement is equal to cementitious product when the net balance of clinker sold and purchased is neutral (at a corporate level).
- **CEN** : European Committee for Standardization, Comité Européen de Normalisation.
- **Clinker**: Intermediate product in cement manufacturing and the main substance in cement. Clinker is the result of calcination of raw materials in the kiln.
- **Climate neutral:** CO_2 emissions that are equal to the amount of CO_2 absorbed from the atmosphere during the growth of biomass.
- **Company level**: Used for the performance indicators, on cement or cementitious product, at the level of a company, possibly including several clinker and/or grinding installations, for the production of cement or cementitious products.
- **CSI**: Cement Sustainability Initiative
- **Gross CO_2 emissions**: All direct CO_2 emissions (excluding on-site electricity production) excluding CO_2 emissions from biomass, which are considered climate neutral.
- **Installation or plant level**: Used for any performance indicator, excluding cement or cementitious product, at the level of an individual installation for the production of clinker and/or cement.
- **Net CO_2 emissions**: Gross CO_2 emissions minus emissions from alternative fossil fuels.
- **System limits of CO_2 emissions**: Direct CO_2 emissions related to the production of clinker and cement according to the WBCSD – CSI Cement CO_2 Monitoring & Reporting Protocol, excluding emissions from on- and off- site electric power production.
- **Traditional fuels**: Fossil fuels defined by Intergovernmental Panel on Climate Change (IPCC) guidelines, mainly including: coal, petcoke, lignite, shale, petroleum products and natural gas.
- **WBCSD**: World Business Council for Sustainable Development

8.4 References and resources

Battelle (2002): *Towards a sustainable cement industry*, study made on behalf of the WBCSD. Available on www.wbcsdcement.org.

CSI (2005): WBCSD Cement Sustainability Initiative; *The Cement CO_2 Protocol: CO_2 Accounting and Reporting Standard for the Cement Industry*; June 2005.

CSI (2009): Cement Industry Technology Roadmaps (in preparation)

IEA (2007): *Tracking Industrial Energy Efficiency and CO_2 Emissions*, IEA 2007.

McKinsey (2009): *Pathways to a low-carbon Economy*, version 2 of the *Global Greenhouse Gas Abatement Cost Curve*, McKinsey & Company, January 2009.

USGS (2005) data on global cement production by country is available at http://minerals.usgs.gov/minerals/pubs/commodity/cement/cemenmyb05.pdf

WWF (2008): *A blueprint for a climate friendly cement industry*, by Nicolas Müller and Jochen Harnisch, Ecofys Germany, December 2008.

8.5 Participants

Name of GNR participants	
AALBORG PORTLAND	HOLCIM
ASH GROVE CEMENT	ITALCEMENTI
BUZZI UNICEM	KIRCHDORFER
CALME	LAFARGE
CEMENT HRANICE	LEUBE
CEMENTI DELLA LUCANIA	PORTLAND VALDERRIVAS
CEMENTI MOCCIA	QUINN GROUP
CEMENTI ZILLO	SACCI
CEMENTIR	SCG CEMENT
CEMENTIROSSI	SCHRETTER
CEMENTOS MOLINS	SECIL
CEMENTOWNIA ODRA	SHREE CEMENT
CEMENTOWNIA WARTA	TAIHEIYO
CEMEX	TARMAC
CIMALUX	TITAN
CIMENTOS LIZ	VDZ
CIMPOR	VICAT FRANCE
COLACEM	VICAT SWITZERLAND
CRH	VOTORANTIM
DYCKERHOFF POLSKA	WOPFINGER
GMUNDNER	WUP
GRASIM CEMENT	WOPFINGER
HEIDELBERG CEMENT	WUP

For a list of countries, regions and economic clusters, please see www.wbcsdcement.org/CO2data

About the WBCSD

The World Business Council for Sustainable Development (WBCSD) brings together some 200 international companies in a shared commitment to sustainable development through economic growth, ecological balance and social progress. Our members are drawn from more than 36 countries and 22 major industrial sectors. We also benefit from a global network of 58 national and regional business councils and partner organizations.

Our **mission** is to provide business leadership as a catalyst for change toward sustainable development, and to support the business license to operate, innovate and grow in a world increasingly shaped by sustainable development issues.

About the CSI

The Cement Sustainability Initiative (CSI) is a global effort by 18 leading cement producers. Headquartered in 14 countries, they have operations in more than 100 countries. Collectively these companies account for about 30% of the world's cement production, and range in size from very large multinationals to smaller local producers. All CSI members have integrated sustainable development into their business strategies and operations, as they seek strong financial performance with an equally strong commitment to social and environmental responsibility. Over its 10-year history, the CSI has focused on understanding, managing and minimizing the impacts of cement production and use by addressing a range of issues including: climate change, fuel use, employee safety, airborne emissions, concrete recycling, and quarry management.

Project Director: Howard Klee, (klee@wbcsd.org)
Design: WBCSD Cement Sustainability Initiative (CSI)
Photo credits: CSI participating companies

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