CO_2 EMISSIONS FROM CEMENT PRODUCTION

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ABSTRACT

Cement is an important construction ingredient produced in virtually all countries. Carbon dioxide (CO_2) is a by-product of a chemical conversion process used in the production of clinker, a component of cement, in which limestone ($CaCO_3$) is converted to lime (CaO). CO_2 is also emitted during cement production by fossil fuel combustion and is accounted for elsewhere. However, the CO_2 from fossil fuels is accounted for elsewhere in emission estimates for fossil fuels. The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (*IPCC Guidelines*) provide a general approach to estimate CO_2 emissions from clinker production, in which the amount of clinker produced is multiplied by the clinker emission factor.

The *IPCC Guidelines recommend two possible methods for calculating the clinker emission* factor. The first method is to use the IPCC default value for the fraction of lime in clinker. The second method is to calculate the average lime concentration in clinker by collecting data on clinker production and lime fraction by type. The *IPCC Guidelines* state that the difference between the default value and a value based on collected data is expected to be small. If clinker production data are not available, it is recommended that countries back-calculate clinker production from the cement data while applying a correction factor for clinker imports/exports. Once an estimate has been derived, emissions can be estimated by means of the clinker emission factor.

The IPCC recommends using clinker data, rather than cement data, to estimate CO_2 emissions because CO_2 is emitted during clinker production and not during cement production. If clinker is traded internationally, using cement production data results in a biased emissions estimate because the cement could potentially be produced from clinker that was made in another country. Although clinker data are the preferred data source, cement data may be more readily available in some countries. In this case, the recommended approach is to estimate the fraction of clinker in the cement and back-calculate clinker production.

Quality assurance and quality control activities should be implemented at several stages in the emission estimation process. At the plant level, key activities include internal quality control on production data and emission factors, as well as documenting data and methods for reviewers. The inventory agency must ensure the accuracy of plant submissions as well as the compiled inventory. It is also responsible for providing documentation and sufficient information to the United Nations Framework Convention on Climate Change (UNFCCC). One or more types of external review may also be appropriate.

1 INTRODUCTION

1.1 Nature, magnitude, and distribution of source

Overview of Cement Production

Cement is an important construction ingredient around the world, and as a result, cement production is a significant source of global carbon dioxide (CO_2) emissions, making up approximately 2.4 percent of global CO_2 emissions from industrial and energy sources (Marland et al., 1989). Cement is produced in large, capital-intensive production plants generally located near limestone quarries or other raw carbonate mineral sources as these sources are the principal raw materials used in the cement production process. Because the production plants are expensive, the number of plants in a country is generally limited (less than 100). Carbon dioxide is emitted as a by-product of clinker production, an intermediate product in cement manufacture, in which calcium carbonate ($CaCO_3$) is calcinated and converted to lime (CaO), the primary component of cement. CO_2 is also emitted during cement production by fossil fuel combustion. However, the CO_2 from fossil fuels is specifically accounted for in emission estimates for fossil fuels.

Process Description

Carbon dioxide is released during the production of clinker, a component of cement, in which calcium carbonate ($CaCO_3$) is heated in a rotary kiln to induce a series of complex chemical reactions (*IPCC Guidelines*). Specifically, CO_2 is released as a by-product during calcination, which occurs in the upper, cooler end of the kiln, or a precalciner, at temperatures of 600-900°C, and results in the conversion of carbonates to oxides. The simplified stoichiometric relationship is as follows:

$$CaCO_3 + \text{heat} \rightarrow CaO + CO_2$$

At higher temperatures in the lower end of the kiln, the lime (CaO) reacts with silica, aluminum and iron-containing materials to produce minerals in the clinker, an intermediate product of cement manufacture. The clinker is then removed from the kiln to cool, ground to a fine powder, and mixed with a small fraction (about five percent) of gypsum to create the most common form of cement known as Portland cement. Masonry cement is generally the second most common form of cement. Because masonry cement requires more lime than Portland cement, masonry cement generally results in additional CO_2 emissions.

2 METHODOLOGICAL ISSUES

2.1 Selection of good practice methods

The *IPCC Guidelines* provide a general approach to estimate CO_2 emissions from clinker production, in which the amount of clinker produced is multiplied by an emission factor. Thus the basic equation to estimate CO_2 emissions from clinker production is:

EQUATION 1

$$\text{Activity/Production Data} \bullet \text{CKD Corrections Factor} = CO_2 \text{ Emissions from Clinker}$$

Where CKD stands for Cement Kiln Dust.

Because masonry cement requires additional lime, the *IPCC Guidelines* provide an equation, based on masonry cement production parameters, to estimate CO_2 emissions resulting from the additional lime. The equation, and its components, is presented in Box 1.

BOX 1

IPCC METHODS

Masonry Cement Production Data

Masonry cement, in contrast with Portland cement, requires additional lime. To account for this, the *IPCC Guidelines* provide an equation, based on masonry cement production parameters, to estimate CO_2 emissions resulting from the additional lime. The equation is illustrated below.

EQUATION 2

CO_2 (tons) from CaO added to masonry cement =

a ● (all cement production) ● ((1-1/(1 + b)) ● c) ● 0.785

Where:

a = fraction of all cement produced that is masonry cement (e.g., 0.05-0.2)

b = fraction of weight added to masonry cement by non-plasticiser additives such as lime, slag, and shale (e.g., 0.004, 0.006)

c = fraction of weight of non-plasticiser additives that is lime (e.g., 0.7-0.9)

a ● (all cement production) = masonry cement production

((1-1/(1+b)) ● c) = fraction of lime in masonry cement not attributable to clinker

((1-1/(1+ b)) ● c) ● 0.785 = an emission factor of CO_2 from masonry cement additives

2.2 Emission factors

Estimating emissions generally involves two emission factors: an emission factor for clinker production and an emission factor for Cement Kiln Dust (CKD) production.

2.2.1 Clinker emission factor

The clinker emission factor is the product of the fraction of lime in the clinker multiplied by the ratio of the mass of CO_2 released per unit of lime. This is illustrated below:

EQUATION 3

$$EF_{clinker} = \text{fraction CaO} \bullet (44.01 \text{ g/mole } CO_2 / 56.08 \text{ g/mole CaO})$$

or

EQUATION 4

$$EF_{clinker} = \text{fraction CaO} \bullet 0.785$$

The multiplication factor (0.785) is the molecular weight ratio of CO_2 to CaO in the raw material mineral calcite ($CaCO_3$), from which most or all of the CaO in clinker is derived. CaO content can show variations by country of origin and facility.

The *IPCC Guidelines* recommends two possible methods for calculating the emission factor. The Tier 1 method uses the IPCC default value for the fraction of lime in clinker, which is 64.6 percent. This results in an emission factor of 0.507 tons of CO_2/ton of clinker, as illustrated below:

EQUATION 5

$$EF_{clinker} = 0.646 \bullet 0.785 = 0.507$$

The Tier 2 method is to calculate the average lime concentration in clinker by collecting data on clinker production and lime fraction by type. The difference between the default value and a value based on collected data is expected to be small.

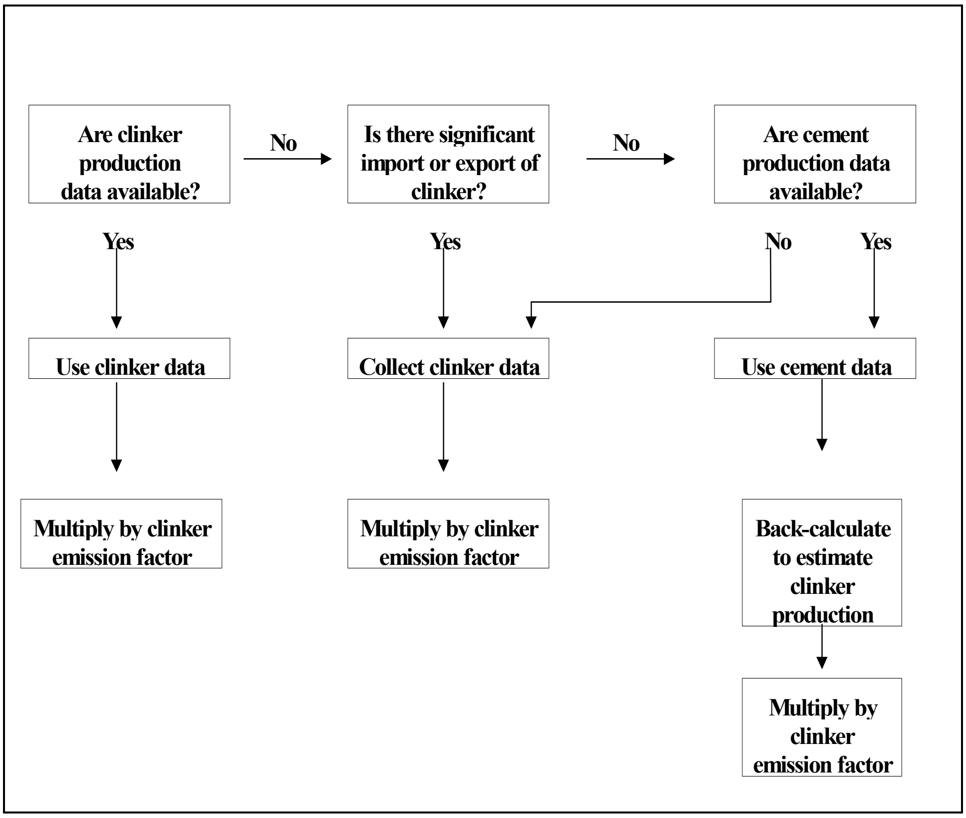
2.3 Activity data

2.3.1 Clinker data

IPCC recommends using clinker data, rather than cement data, to estimate CO_2 emissions because CO_2 is emitted during clinker production (not cement production). Also, if clinker is traded internationally, using cement production data creates biased emission estimates because the cement could potentially be produced from clinker manufactured in another country. Furthermore, the amount of clinker in other types of cement, such as blended and natural cement, is highly variable and difficult to estimate.

If cement data are already available and clinker data are not available, the recommended method is to estimate the fraction of clinker in the cement and back-estimate clinker production. Figure 1 provides a simple decision aid illustrating preferred methods.

Figure 1 Preferences for selecting the appropriate production data



2.4 Uncertainty

Parallel to the IPCC sector-specific experts meetings on *good practice guidance*, the IPCC is completing a programme of work on emissions inventory uncertainty. This work will result in recommendations to the UNFCCC on approaches to assessing and managing uncertainty. During the IPCC Inventory Experts Group Meeting in Paris (October 1998), technical experts in the uncertainty programme came up with a series of questions to be answered in the sectoral meetings. Specifically, the sectoral experts meetings should provide answers to these questions in the individual source context. The questions are listed in the general background paper.

2.5 Completeness

Cement is produced in capital-intensive plants often located near limestone ($CaCO_3$) quarries. The number of plants is generally low (less than 100) and the plants are easy to locate and monitor, making it highly feasible for countries to collect clinker or cement production data from each plant in the country. To facilitate creating an up-to-date inventory, countries should monitor imports and exports of clinker.

2.6 Other important issues

2.6.1 Baseline

An emissions baseline is an important component of an inventory programme. Developing a baseline requires collecting and compiling clinker and CKD production data during or following the baseline period. As mentioned previously, a complete inventory should include data collected from each plant. Difficulties may arise when:

- Individual plants have not maintained records during the baseline period; or
- Individual plants that produced clinker and CKD during the baseline period are no longer in operation.

In such cases, it may be necessary to estimate baseline clinker and CKD production. Approaches for estimating production figures may include:

- Estimating clinker and CKD production data based on plant production capacity and the utilisation rate; or
- Calculating the estimates using national production data from the baseline period.

If production data are estimated using plant production capacity and plant utilisation rates, care should be taken to account for time during which plants are not operating (i.e., down-time).

2.6.2 Cement Kiln Dust (CKD)

CO_2 is also emitted during the calcination of cement kiln dust (CKD) in the kiln. CKD is a by-product of the kiln process and a portion of the CKD is placed back in the kiln and incorporated into the clinker. The remaining portion is lost – placed in a landfill or used for other purposes. The lost CKD represents additional CO_2 emissions not accounted for in the clinker emissions estimate.

The recommended method to estimate the additional CO_2 emissions from the lost CKD is to multiply an emission factor by the amount of lost CKD. However, CKD production data are usually not available. The CO_2 from the lost CKD is generally equivalent to about 2-6 percent of the total CO_2 emitted from clinker production. If data are not available, it is recommended that countries select a percentage between 2-6 percent and multiply the percentage by the estimate of CO_2 emissions from clinker production. This yields an estimate of CO_2 from the lost, calcined CKD.

3 REPORTING AND DOCUMENTATION

3.1 Current IPCC reporting guidelines

This section provides information on the current *IPCC Guidelines*. The *IPCC Guidelines* are used to guide countries in the preparation and submissions of annual greenhouse gas emissions inventories to the UNFCCC Secretariat. The Guidelines establish:

- Standard tables, definitions, units, and time intervals for reporting all types of emissions;
- Necessary documentation to enable comparison of national inventories, including worksheets, major assumptions, methodological descriptions and enough data to allow a third party to reconstruct the inventory from national activity data and assumptions, and
- An uncertainty assessment.

CO_2 emissions from cement production are reported in *IPCC Guidelines* Volume 1, Table 2: Sectoral Report for Industrial Processes, which calls for entries for each source for emissions totals of carbon dioxide, methane, nitrous oxide, precursor gases (NO_x, CO, NMVOCs, SO_2), HFCs, PFCs, and SF_6.

CO_2 emissions from cement production are reported under the IPCC category 2A1, which derives from the following classification scheme:

2: Industrial processes

2A: Non-Metallic Mineral Products

2A1: Cement Production

3.2 Confidential business information

The issue of confidential business information (CBI) may make reporting national inventory in a transparent manner highly problematic. Countries may need to create confidential tracking and reporting systems, or, alternatively, to report the number of plants with an aggregated national total. If only one plant exists, CO_2 emissions from cement production may need to be combined with CO_2 emissions from other industrial sources, because reporting emissions from the one cement plant would release potentially confidential information.

4 INVENTORY QUALITY

4.1 Introduction

Inventory quality assurance and quality control (QA/QC) is a process integral to the development of a credible inventory. A well-developed and well-implemented quality assurance programme fosters confidence in the final inventory results regardless of the purpose and goal of the inventory. A successful quality assurance programme requires internal quality control procedures and an unbiased, external review and audit. The internal QC activities are designed to ensure accuracy, documentation and transparency. The external review process is designed to minimise errors that occur in the preparation of emissions inventories and reduce or eliminate potential inherent bias. Figure 2 outlines the flow of information and processes followed at each stage of the process.

Figure 2 Inventory QA/QC Process

	Cement Plant
Internal QC:	Plant-level measurement and calculations
Documentation:	Plant-level information provided to the government agency, and results of internal QC
	⇩
	Government Agency
Review/QA:	Plant-level inputs
Internal QC:	Compilation of national inventory from plant-level data
Documentation:	Results of compilation and results of QA/QC
Reporting:	Official submission to UNFCCC
	⇩
	External Review
External Review:	External audit, stakeholders, peer and public review of inventory results, external verification against other data etc.
Documentation:	Results of external review
	⇩
	UNFCCC Secretariat
External Review:	Requires standard format and transparency – ensure consistency with other inventories and external data

4.2 Internal inventory QA/QC systems

4.2.1 Plant-level activities

Plant-Level Data QC

The personnel at each plant are responsible for determining the QC procedures unique to that plant. Plant data includes production data, as well as data on the amount of lime and other substances added. Performing QC on plant data also involves cross-checking the data. Examples include cross-checking the amount that is produced with the amount that is shipped, or cross-checking the amount of clinker produced with the amount of cement produced (if cement is produced in the same plant). A QC procedure should also include a written procedure for how data are collected, records of current and historical plant data and estimates of accuracy and precision.

Plant-Level Documentation

Documentation is a crucial component of the review process, because it enables reviewers to identify mistakes and suggest improvements. Among others, the following information is needed for the reviewing/auditing agency:

- A detailed description of data collection methods, and
- A discussion of potential biases involved in data collection, such as a discussion of possible reasons for incorrect production data. For example, producers may give incorrect data to avoid environmental regulations or government taxes. If there is potential bias, the discussion should include suggestions on how to overcome this bias.

In addition, a standardised reporting form is recommended to provide transparent information on production. Given that data are collected from each production plant, the reporting form should be signed and certified by an appropriate plant representative.

4.2.2 Inventory Agency Level Activities

Inventory Agency Review (QA) of Plant-Level Information

Before accepting plant-level emissions data, the inventory agency should assess plant data, including both production data and data on the amount of lime and other substances added to the clinker if such information is available. This review involves close cooperation with plant owners and personnel to ensure that production data are accurate. The assessment should include a review of records, comparison with historical plant data, identification of potential bias in the data and recommendations for improvement, such as better data management methods.

Inventory Agency QC on Compiling National Emissions

In addition to the thorough quality assessment of data discussed above, the inventory agency should ensure that the process of aggregating data to develop the national inventory undergoes quality control. This should include:

- Ensuring that all data are included, and
- Identifying any anomalies and/or patterns through comparison with industry trends.

Inventory Agency Documentation on Compiling National Emissions

For the CO_2 emission inventory for cement production, a QA/QC management plan should address the specific items required to perform audits and reviews. Examples of the types of information needed for documentation and external audit include:

- A detailed description of the inventory methodology;
- Identification of the required input parameters and the methodology used to obtain these input parameters, and
- Frequency of data collection, estimation and results of accuracy and precision determinations.

4.3 External inventory QA/QC systems

External QA activities include a planned system of review and audit procedures conducted by personnel not actively involved in the inventory development process. The key concept is an independent, objective review to assess the effectiveness of the internal QC programme, the quality of the inventory and to reduce or eliminate any inherent bias in the inventory processes.

Several types of external reviews or audits may be appropriate such as:

- **Third party audit**

  An audit of the documentation and calculations by an accredited organisation, expert or independent third party ensures that each number is traceable to its origin. Given that much of the information used in developing CO_2 emission estimates from cement production may be proprietary, a third party audit that protects confidentiality may be necessary.

- **Expert (peer) review**

  A detailed peer review would be appropriate when a procedure for determining CO_2 emissions is first adopted or revised; it would not be needed on an annual basis. Such a review is designed to ensure that the methodology accurately represents the plant's particular situation, is as rigorous as possible and that the data and assumptions reflect the best available information.

- **Stakeholder review**

  Review by cement producing companies, industrial organisations and government can provide a forum for review of the methods used.

- **Public review**

  Some countries make their entire inventory available for public review and comment. This process may result in a range of comments and issues on a broader level than other review processes.

Confidential Business Information Issues

Reviewing production data involves examining data from each plant. However, given that the plant-level production data are often considered confidential, some producers may be unwilling to release production data, or to have production data released to the public.

5 CONCLUSIONS

The key issues relate to the methodology used to calculate clinker emissions, availability of CKD data as well as confidentiality. The emissions equation assumes that all CaO in clinker is derived from $CaCO_3$. As non-carbonate sources could be potentially used by manufacturers, possible margins of error from such an assumption should be investigated. Availability of CKD data is usually lacking and the possibility of using default CKD correctional factors is to be further analysed. The confidential nature of business practices could also hamper the reporting of a national inventory in a transparent manner. Options could include the development of confidential tracking systems or the aggregation of the national total of cement production plants.

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