Stiftelsen Østfoldforskning

Documentation of the Environmental Benefits to Society of Using Waste Derived Fuels at Norcem Brevik

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Fredrikstad, March 2006
OR.15.05

REPORT SUMMARY

Report no.: OR 15.05

ISBN no.: 978-82-7520-551-1
82-7520-551-4
ISSN no.: 0803-6659

Report type: Commissioned report

Report title: Documentation of the Environmental Benefits to Society of Using Waste derived Fuels at Norcem Brevik

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Project number: 211300 | **Project title:** Norcem, samfunnsnytte

Commissioned by: Norcem
Company contact(s): Bjørn Mørck and Per Brevik

Summary: This study documents the environmental benefits for society that arise from the use of waste derived fuels in Norcem Brevik's cement production, compared to alternative treatment of the waste. The comparison performed is based on a functional unit, which can be described as follows: *The alternative energy requirement for a year's production of clinker (the part of the total energy requirement that is replaced by waste derived fuels in 2005) at Norcem Brevik and waste management of 120 920 tonnes of waste of a given composition*[1] *and production of 517 TJ energy*[2].

The study concludes that Norcem Brevik has reduced greenhouse gas emissions (approx. 400 000 - 440 000 tonnes CO_2 per year) by burning waste derived fuels as a substitute for coal, due to:

- reduction of the amount of waste that is sent to landfill (no CH_4 emissions);
- less extraction of coal is needed;
- coal is replaced with waste energy sources;
- there is a high content of biomass in the waste energy sources (no fossil-based CO_2 emissions).

Incineration of waste in Norcem Brevik's cement kiln, avoids waste ash from municipal waste incineration, which would have been approx. 13 000-20 000 tonnes per year.
Treatment of hazardous waste at Norcem Brevik gives the following additional benefits:

- the cement kiln ensures the destruction of components that could form toxic emissions in the lower temperatures used in municipal waste incineration facilities (e.g. dioxins);
- heavy metals do not leach from cement and concrete products, thus using hazardous wastes (high heavy metal content) for cement production is a safe disposal route.

Norcem Brevik could experience additional improvements in emissions if the company had not taken on the societal burden of treating hazardous waste. If Norcem switched from waste fuels to biomass fuels they could reduce their greenhouse gas emissions from fuel use by 9% of the fuel related emissions.

Keywords:	**Confidentiality**	**Number of pages**
Cement; Waste Management; Scenarios	**This page:** Open **This report:** Open	**Report: 33** **Appendices: 7**

Approved Date:
15th March, 2006

Project Manager
(sign)

Research Manager
(sign)

[1] See Table 2.1 for the relevant amounts and types of hazardous waste.
[2] See Table 2.2 for the relevant amounts of energy included.

Contents

Glossary

Avoided energy	Energy that would have been produced and consumed, if it had not been replaced by alternative energy produced in the product system analysed. This 'avoided energy' is often shown as having negative environmental impacts, this as the replacement of this avoided energy often leads to a reduction in environmental impacts that would otherwise have occurred. These avoided impacts are thus allocated to the product system in the form of negative impacts, or credits.
CCA wood	Wood that has been impregnated using Copper, Chromium and Arsenic (e.g. wood used for building verandas). This must be disposed of as hazardous waste.
CO_2	Carbon dioxide
Energy Source	The source of energy from which energy carriers are made (e.g. crude oil).
Energy Carrier	This is the energy product that is made from the energy source (the form in which the energy is consumed, e.g. diesel).
EPIs	Environmental Performance Indicators, or key environmental data for management and reporting purposes.
EPDs	Environmental Product Declarations, Type III. Environmental product information based on LCA methodology, presented in a standard format (administered by 'Næringslivets Stiftelse for Miljødeklarasjoner' in Norway) according to ISO14025 *Type III Environmental Declarations (EPD).*
Functional unit (FU)	The functional unit represents a product's performance according to a specific user's requirements. This unit should reflect the product's function and life span. It should, as far as possible, not allow subjective interpretations and should represent the beneficial value of the system. A system can have several functions, and the functional unit shall therefore reflect the function or functions being assessed. All inputs and outputs in the system are related to the functional unit. Example: the functional unit for drink packaging can be the amount of packaging needed to distribute 1000 litres of drinks to the customer.
Global warming potential (GWP)/ global climate change/ greenhouse effect	The chemical composition of the atmosphere is one of the most important factors that influence the climate on Earth. The atmosphere is mostly composed of nitrogen and oxygen, but also contains so-called greenhouse gases. These gases

	allow most of the energy from the sun to pass through, which comes in the form of short wavelength radiation, but at the same time slowing down the returning radiation from the Earth (in the form of infrared long wave heat radiation). The increased concentration of greenhouse gasses thus leads to an increase in the temperature in the lower levels of the atmosphere, called the troposphere. The most important natural greenhouse gases are steam, carbon dioxide (CO_2) and methane (CH_4). These gases have their natural cycle within the atmosphere, or between the atmosphere and the sea, soil or biosphere. Human activity has lead to emissions that contribute to an increase in concentration of these gases, with the resulting increase in global warming. Altogether, greenhouse gases amount to less than 1 percent of the atmosphere, but without greenhouse gases the average temperature on the Earth would be -18 ^oC and the worlds oceans would be covered in ice. Greenhouse effect or global climate change is expressed as grams CO_2 equivalents (Goedkoop, M. 2000).
Global climate change	See Global warming potential.
Greenhouse effect	See Global warming potential.
LCA	Life Cycle Assessment.
LCI	Life Cycle Inventory. This is a detailed mass and energy balance for the product system based on the functional unit.
LHV	Lower Heating Value, which can be described as the available energy content of a fuel (without making use of the heat content in the exhaust from fuel combustion).
Methane	CH_4
RDF	The abbreviation RDF stands for "Refuse Derived Fuels". A trade name for solid fuel made from waste products.
Trp	Abbreviation used for 'transport'.

1 Summary

This study documents the environmental benefits for society that arise from the use of different types of waste derived fuels in Norcem Brevik's cement production, compared to alternative treatment of the waste. The comparison performed is based on a functional unit, which can be described as follows:

The alternative energy requirement for a year's production of clinker (the part of the total energy requirement that is replaced by waste derived fuels in 2005) at Norcem Brevik and waste management of 120 920 tonnes of waste of a given composition[1] *and production of 517 TJ energy*[2].

The study concludes that Norcem Brevik has reduced greenhouse gas emissions (approx. 400 000 - 440 000[3] tonnes CO_2 per year) by burning waste derived fuels as a substitute for coal, due to:

- reduction of the amount of waste that is sent to landfill (no CH_4 emissions);
- less extraction of coal is needed;
- coal is replaced with waste energy sources;
- there is a high content of biomass in the waste energy sources (no fossil-based CO_2 emissions).

Incineration of waste in Norcem Brevik's cement kiln, avoids waste ash from municipal waste incineration, which would have been approx. 13 000-20 000 tonnes per year. Treatment of hazardous waste in Norcem Brevik's gives the following additional benefits:

- the cement kiln ensures the destruction of components that could form toxic emissions in the lower temperatures used in municipal waste incineration facilities (e.g. dioxins);
- heavy metals do not leach from cement and concrete products, thus using hazardous wastes (high heavy metal content) for cement production is a safe disposal route.

Norcem Brevik could experience additional improvements in emissions if the company had not taken on the societal burden of disposing of waste. If Norcem switched from waste fuels to biomass fuels they could reduce their greenhouse gas emissions from fuel use by 9% of the fuel related emissions.

[1] See Table 2.1 for the relevant amounts and types of hazardous waste.
[2] See Table 2.2 for the relevant amounts of energy included.
[3] 420 000 tonnes CO_2 is equivalent to the emissions per year for 35 000 people in Norway [21] (about the same as the population of Bodø [22]), or the emissions for approximately 134 000 private cars [23] in Norway (assuming 16 000 km driven per annum).

2 Background for the study

Norcem Brevik's current energy sources are a mixture of different fuels. Part of the coal requirement for the clinker kiln has been replaced with alternative fuels. The alternative fuels used include waste fractions. These waste fractions are a mixture of fossil-based materials and biomass.

Norcem want to document the environmental benefits for society that arise from the use of different types of waste derived fuels in production, compared to alternative treatment of the waste.

The comparison performed is based on a functional unit, which can be described as follows:

The alternative energy requirement for a year's production of clinker (the part of the total energy requirement that is replaced by waste derived fuels in 2005) at Norcem Brevik and waste management of 120 920 tonnes of waste of a given composition[4] and production of 517 TJ energy[5].

- 120 920 tonnes correspond to the amount of waste derived fuels used as an energy source at Norcem[7]
- 517 TJ corresponds to the energy that can be generated by alternative waste management of these 120 920 tonnes of waste (as described in Table 2.2).

The composition and relevant properties of the waste is given in Table 2.1 [1,2].

Table 2.1: Waste derived fuels used at Norcem Brevik in 2004 and 2005.

Name	tonnes/year		MJ/kg	g fossil CO_2/MJ
	2004	2005		
Waste Oil	1 418	1 120	34.3	74
Solid hazardous waste	9 218	13 246	13.6	74
Liquid hazardous waste	10 653	11 722	16.7	74
RDF	35 728	75 676	14.2	8.7
Sawdust	3 921	4 853	18.2	
CCA wood	637	1 770	14.7	
Plastic	820	743	37.7	75
Animal meal	4 925	11 790	17.2	
Total	**67 320**	**120 920**		

More information about the energy assumed produced if the waste derived fuels are not used at Norcem Brevik, but go to from alternative waste management (municipal waste incineration), is given in Table 2.2.

[4] See Table 2.1 for the relevant amounts and types of hazardous waste.
[5] See Table 2.2 for the relevant amounts of energy included.

Table 2.2: Energy assumed produced from alternative waste management of the waste derived fuels used at Norcem Brevik in 2005.

	Amount of energy produced, alternative waste management (MJ)
Waste Oil	26 916 100
Solid hazardous waste	126 167 753
Liquid hazardous waste	137 417 475
RDF [6]	
Sawdust	57 450 673
CCA wood	16 859 197
Plastic	20 997 849
Animal meal	131 550 721
Total	**517 359 767**

3 Goals

The goal of the project can be summarised as follows:

- Document the environmental benefits for society that arise from the use of different types of waste derived fuels in production.

4 Methodology and organisation

The study is carried out using life cycle assessment (LCA) methodology based on the ISO-standards 14040-43. A short introduction to LCA methodology is given in this chapter, with more detailed information available in Appendix 9.1.

4.1 Short introduction to LCA - methodology

A life cycle assessment of a product is defined as: "A systematic survey and assessment of health, environmental and resource effects throughout the whole life cycle of a product, or product system, from 'cradle to grave' (from extraction of raw materials to final disposal)" [3]. This is based on a *product system*, and assesses environmental and resource aspects of the system in relation to a defined *functional unit*, which is the unit that describes the product's performance in relation to particular user needs.

The life cycle assessment shall encompass all of the processes and activities that are part of the product system, which as a whole contribute to fulfilling the function or functions that the product system should fulfil.

[6] It is assumed that the materials used to make RDF are sent to landfill if not used at Norcem Brevik.

An example of a life cycle model for a product system is shown in the figure below.

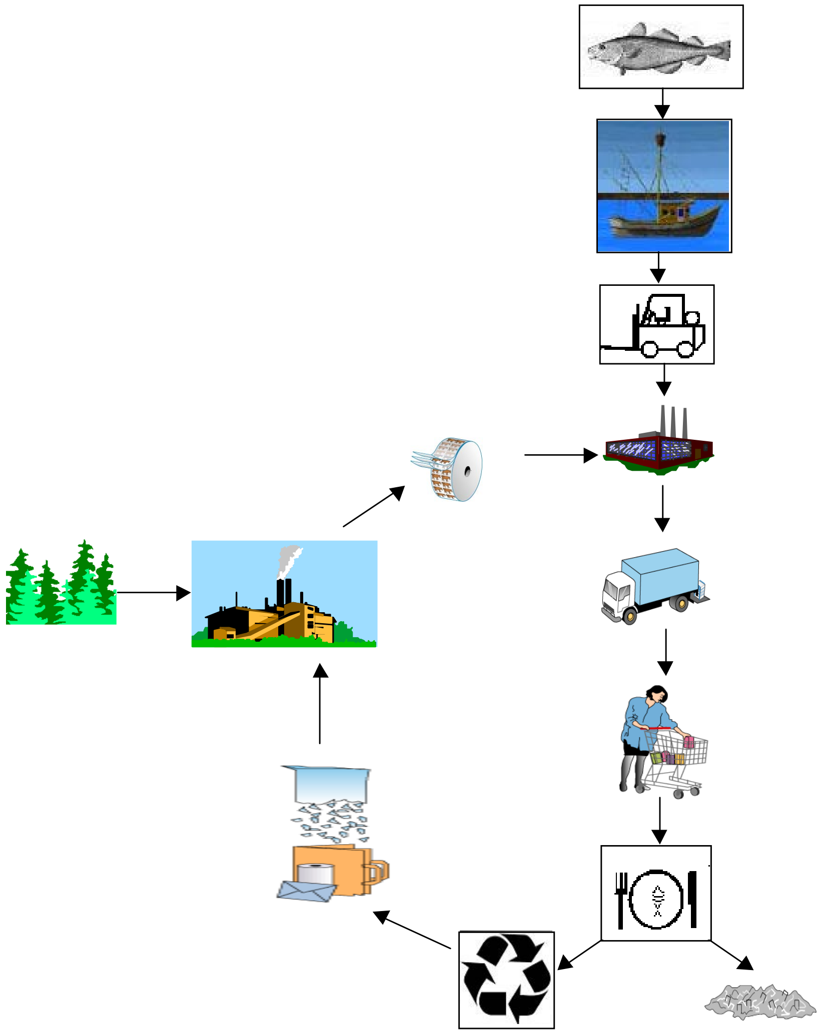


Figure 4.1: Example of a life cycle model for a product system for a fish product (incl. packaging).

Three central points in a life cycle assessment are:

- one examines the whole technical system required to produce, use and dispose of the product (system analysis), not just the product as such
- one examines the whole material cycle along the product's value chain, not just a single operation, or manufacturing process for a product
- one examines all of the relevant environmental and health affects for the whole system, not just for an individual environmental factor.

This gives a more holistic approach to health, environmental and resource problems than that we have witnessed before. Previously the focus has been upon individual factors, or processes.

The SimaPro 5.1 software[7] has been used in order to carry out the analyses performed [4].

[7] SIMAPRO - International LCA software tool, which includes a database of environmental emissions data from extraction, production and use of different energy carriers and materials.

4.2 Organisation

Østfold Research Foundation has worked closely with Bjørn Mørck, Per Brevik and Lars-André Tokheim, Norcem. They have actively participated in the collection of data and the quality assurance of the data used. Norcem has (Bjørn Mørck, Per Brevik and Lars-André Tokheim) had the important task of quality control for the conditions, assumptions, and data used, as well as the results.

The project organisation in Østfold Research Foundation has consisted of the following personnel:

Project manager:	Mie Vold (Senior Research Scientist)
Co-workers:	Anne Rønning (Senior Research Scientist)
	Cecilia Askham Nyland (Senior Research Scientist)
	Hanne Lerche Raadal (Senior Research Scientist)

STØ and Norcem have had 2 meetings during the project period, as well as frequent e-mail and telephone contact.

5 System Description, Conditions and Assumptions Used

Life cycle assessments have been carried out in order to calculate the environmental impacts arising from the systems analysed. The global warming potentials (CO_2 equivalent emissions) for these systems are calculated based on the following functional unit:

Functional unit:

The alternative energy requirement for a year's production of clinker (the part of the total energy requirement that is replaced by waste derived fuels in 2005) at Norcem Brevik and waste management of 120 920 tonnes of waste of a given composition[8] *and production of 517 TJ energy*[9].

The scenarios analysed cover different fuel mixes for waste derived fuels and different forms of energy replaced by the heat generated from alternative waste management routes.

Figure 5.1 illustrates the functional unit for this study and the relationship with the scenarios 'previous' and 'future', which are examined in this study (see Chapter 7 for a detailed explanation of these scenarios).

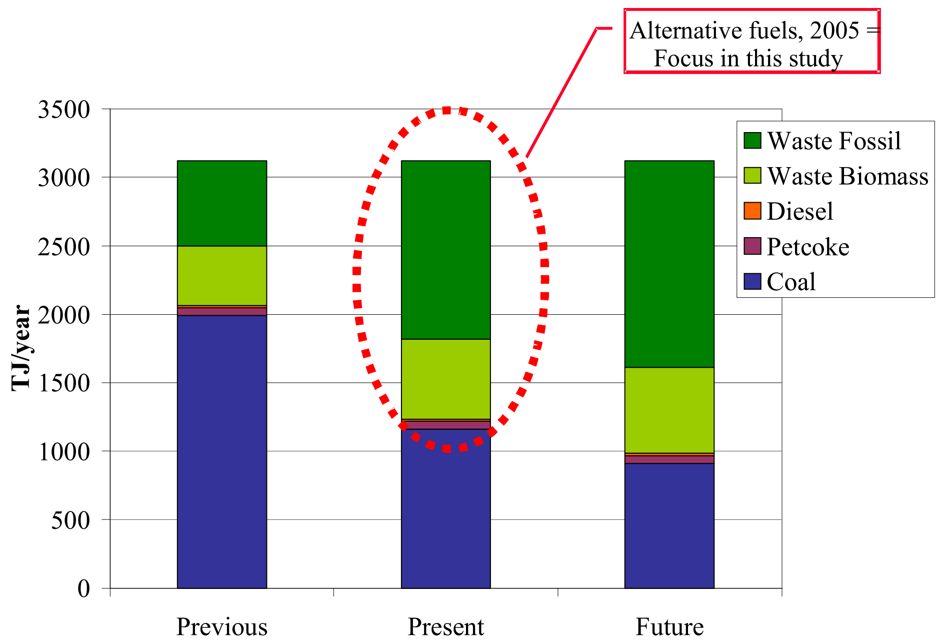


Figure 5.1: The functional unit for this study and the relationship with the scenarios 'previous' and 'future'

[8] See Table 2.1 for the relevant amounts and types of hazardous waste.
[9] See Table 2.2 for the relevant amounts of energy included.

It should be noted that the functional unit and system boundaries chosen focus on the waste energy carriers and the coal that would be required to meet the same energy requirement. This means that the remaining energy carriers, such as coal, petroleum coke, diesel and electricity, that would also be used at Norcem Brevik are not included in the scenarios shown in Chapter 6.1. This is because the contributions from these energy carriers will be the same, independent of the waste management scenario analysed.

Chapter 5.1 gives an overview over the general conditions and data the analyses are based on, while chapters 5.2 - 5.3 give more detailed descriptions of the conditions and assumptions used for the systems analysed.

5.1 General conditions, assumptions and data used

In this chapter the general conditions and data the main analyses are based on are described.

5.1.1 Conditions for the main analysis

Choice of environmental parameters
This study focuses solely on the environmental impact category Global Warming Potential (GWP, Greenhouse effect). Other aspects have been considered in a qualitative fashion (e.g. potential production of ash from alternative waste management scenarios).

5.1.2 Data used

Energy carrier electricity
The specific energy mix for electricity data for Norway [5] is used. While the SimaPro database is used for production of electricity from the given energy carrier [4].

Construction and demolition of equipment/buildings etc.
Equipment/buildings etc. are not included, as the environmental impacts arising from these have been proven to contribute an insignificant amount of the total environmental impacts in fossil energy carrier life cycles [6].

Collection and comparison of data
STØ and Norcem have performed the data collection activity in close collaboration. The specific data used for each system is described in more detail in the chapters 5.2-5.3.

The global warming potential data collected is shown in the systems' respective results chapters in this report (chapters 6.1.1-6.1.3) for each of the systems, split up according to the different parts of the life cycle. The global warming potential results for the systems are compared in Chapter 6.1.4.

Properties of the energy carriers used in this study
These can be found in Table 5.1.

Table 5.1: ***Properties (energy and CO_2 content) of the energy carriers used in this study.***

Name	MJ/kg	G fossil CO_2/MJ
Coal	29.3	96
Waste Oil	34.3	74
Solid hazardous waste	13.6	74
Liquid hazardous waste	16.7	74
Refuse Derived Fuels (RDF)[10]	14.2	8.7
Sawdust	18.2	0[11]
CCA wood	14.7	0[11]
Plastic	37.7	75
Animal meal	17.2	0[11]

The total energy use at Norcem Brevik is not included in this study. The functional unit and system boundaries chosen focus on the waste energy carriers and the coal that would be required to meet this energy requirement if the waste energy carriers were not used. This means that the remaining energy carriers, such as coal, petroleum coke, diesel and electricity, that would also be used at Norcem Brevik are not included in the scenarios shown in Chapter 6.1. This is because the contributions from these energy carriers will be the same, independent of the waste management scenario analysed.

5.2 Previous situation, heat energy recovered from waste used in Norwegian Industry.

Figure 5.1 shows the flow sheet for the 'Previous' situation.

[10] Based on 90% biomass
[11] CO_2 emissions from burning biological material do not contribute to the greenhouse effect.

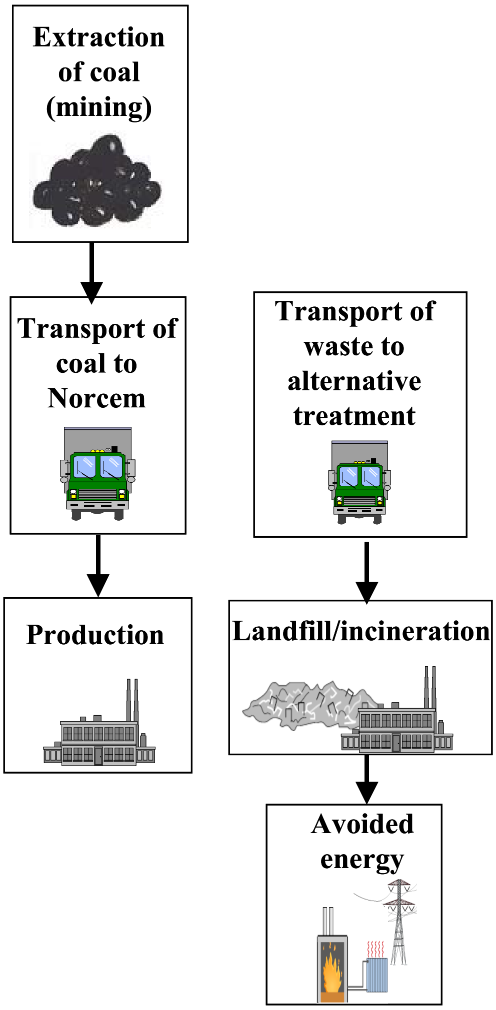


Figure 5.1: ***The system boundaries for the assessment of the 'previous situation'.***

5.2.1 Assumptions, Conditions and References

Table 5.2 gives a summary of the specific assumptions, conditions and references used for the different life cycle stages included in the current situation (2005 is the reference year). The general conditions and assumptions described in Chapter 5.1 also apply here.

Table 5.2: ***Description of the different life cycle stages for the previous situation, heat energy used in Norwegian industry.***

Life Cycle Stages	**Description of the assumptions, conditions and references used.**
Extraction of coal	International coal mining data used from the EcoInvent LCA database [7] (Coal from underground mine UCPTE S) Specific Svalbard data are not used, as these are currently not available.
Transport of Coal to Norcem Brevik	Assumed 2700 km distance by oceanic freighter (distance from Svalbard, estimated using air travel distances from Svalbard – Tromsø –Stavanger - Kristiansand - Oslo [8]). The freight vessel is assumed to return to Svalbard empty.
Production	CO_2 emissions for the coal used at Norcem Brevik (see Table 5.1) are provided by Norcem. These data are used for calculation of annual CO_2 emissions for clinker production (as reported to the Norwegian Pollution Control Authority).
Transport of waste to alternative waste management	Transport of the different waste fractions to alternative waste treatment. Table 5.2 shows the data used for these transport stages of this life cycle.
Alternative treatment	The alternative waste management systems assumed to be used for the relevant wastes. This is incineration for all of the relevant waste streams, with the exception of RDF, which is assumed to be landfilled. Table 5.3 shows the data used for these alternative treatment methods.
Avoided Energy	75% of the energy produced by the alternative incineration plant is assumed to replace energy produced from an oil boiler and 25% replacing Norwegian electricity production. [11, 12, 13, 14]. This is relevant for systems where the heat energy produced is used directly by Norwegian industry. We have assumed that all the energy produced by municipal waste incineration is sold, even though, in reality, the amount of energy replaced may be lower than assumed, as all of the energy produced does not all necessarily get sold. This will depend on fluctuations in demand.
Total	The sum of all of the life-cycle stages (activities) in the system.

Table 5.3: ***Transport data used for transport of the different wastes to alternative treatment.***

Waste	**Distance (km, [9])**	**Description of the data and assumptions used.**
Waste Oil	-	Local treatment assumed.
Solid hazardous waste	750	Transport to Nyborg, Danmark (Kommunekemi). European lorry 32t assumed. One way (no return transport allocated to this system).
Liquid hazardous waste		
RDF	-	Local treatment (RDF comes from a waste management site, so it is assumed that the waste would be managed on site (landfill), if not sent to Norcem Brevik).
Sawdust	30	European lorry 16t assumed. One way (no return transport allocated to this system).
CCA wood	350	Transport to Örebro, Sverige (SAKAB). European lorry 16t assumed. One way (no return transport allocated to this system).
Plastic	65	Distance for transport from Renor Aurskog to Brobekk (Oslo). European lorry 16t assumed. One way (no return transport allocated to this system).
Animal meal	231	Average distance Haugesund-Bergen, Grødaland-Bergen and Stranda-Trondheim. European lorry 16t assumed. One way (no return transport allocated to this system).

Table 5.4: ***Alternative waste management data and assumptions used.***

Waste	**Alternative waste treatment**
Waste Oil	Incineration, energy efficiency: 0.7 [10].
Solid hazardous waste	0.7 [10]
Liquid hazardous waste	0.7 [10]
Sawdust	0.65 [10]
CCA wood	0.65 [10]
Plastic	Incineration, as in [11, 12, 13, 14], assumed ⅔ foil + ⅓ hard plastic. Energy efficiency: 0.75
Animal meal	0.65 [10]
RDF	Landfill. RDF composition: 90% biomass [1]. For calculation of landfill emissions, it is assumed ⅓ of this is food waste and ⅔ fibre-based waste [15]. It is assumed that the remaining 10% is plastic (55% foil, 45% hard/other), [15]. Emissions of methane and CO_2 from landfill are calculated based on this composition and [15, 16, 17].

5.3 Previous situation, waste incineration at Brobekk, Oslo.

The flow sheet for this case is the same as shown in Figure 5.1.

5.3.1 Assumptions, Conditions and References

Table 5.5 gives a summary of the specific assumptions, conditions and references used for the different life cycle stages included in the current situation (2005 is the reference year). The general conditions and assumptions described in Chapter 5.1 also apply here.

Table 5.5: ***Description of the different life cycle stages for the previous situation, Brobekk scenario.***

Life Cycle Stages	**Description of the assumptions, conditions and references used.**
Extraction of coal	International coal mining data used from the EcoInvent LCA database [7] (Coal from underground mine UCPTE S) Specific Svalbard data are not used, as these are currently not available.
Transport of Coal to Norcem Brevik	Assumed 2700 km distance by oceanic freighter (distance from Svalbard, estimated using air travel distances from Svalbard – Tromsø –Stavanger - Kristiansand - Oslo [8]). The freight vessel is assumed to return to Svalbard empty.
Production	CO_2 emissions for the coal used at Norcem Brevik (see Table 5.1) are provided by Norcem. These data are used for calculation of annual CO_2 emissions for clinker production (as reported to the Norwegian Pollution Control Authority).
Transport of waste to alternative waste management	Transport of the different waste fractions to alternative waste treatment. Table 5.2 shows the data used for these transport stages of this life cycle.
Alternative treatment	The alternative waste management systems assumed to be used for the relevant wastes. This is incineration for all of the relevant waste streams, with the exception of RDF, which is assumed to be landfilled. Table 5.3 shows the data used for these alternative treatment methods.
Avoided Energy	All of the energy produced replaces Norwegian electricity production. This is relevant for The Brobekk incineration facility in Oslo. We have assumed that all the energy produced by municipal waste incineration is sold, even though, in reality, the amount of energy replaced may be lower than assumed, as all of the energy produced does not all necessarily get sold. This will depend on fluctuations in demand.
Total	The sum of all of the life-cycle stages (activities) in the system.

Table 5.6: ***Transport data used for transport of the different wastes to alternative treatment.***

Waste	Distance (km, [9])	Description of the data and assumptions used.
Waste Oil	-	Local treatment assumed.
Solid hazardous waste	750	Transport to Nyborg, Danmark (Kommunekemi). European lorry 32t assumed. One way (no return transport allocated to this system).
Liquid hazardous waste		
RDF	-	Local treatment (RDF comes from a waste management site, so it is assumed that the waste would be managed on site (landfill), if not sent to Norcem Brevik).
Sawdust	30	European lorry 16t assumed. One way (no return transport allocated to this system).
CCA wood	350	Transport to Örebro, Sverige (SAKAB). European lorry 16t assumed. One way (no return transport allocated to this system).
Plastic	65	Distance for transport from Renor Aurskog to Brobekk (Oslo). European lorry 16t assumed. One way (no return transport allocated to this system).
Animal meal	231	Average distance Haugesund-Bergen, Grødaland-Bergen and Stranda-Trondheim. European lorry 16t assumed. One way (no return transport allocated to this system).

Table 5.7: ***Alternative waste management data and assumptions used.***

Waste	Alternative waste treatment
Waste Oil	Incineration, energy efficiency: 0.7 [10].
Solid hazardous waste	0.7 [10]
Liquid hazardous waste	0.7 [10]
Sawdust	0.65 [10]
CCA wood	0.65 [10]
Plastic	Incineration, as in [11, 12, 13, 14], assumed ⅔ foil + ⅓ hard plastic. Energy efficiency: 0.75
Animal meal	0.65 [10]
RDF	Landfill. RDF composition: 90% biomass [1]. For calculation of landfill emissions, it is assumed ⅓ of this is food waste and ⅔ fibre-based waste [15]. It is assumed that the remaining 10% is plastic (55% foil, 45% hard/other), [15]. Emissions of methane and CO_2 from landfill are calculated based on this composition and [15, 16, 17].

5.4 Present Situation, waste energy used at Norcem, Brevik.

Figure 5.2 shows the flow sheet for the current situation.

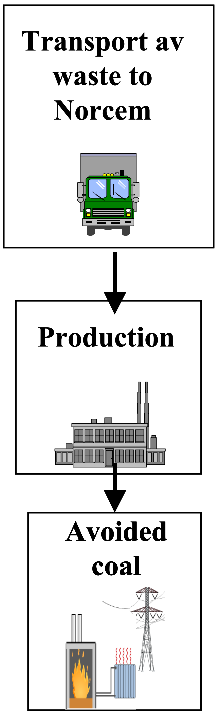


Figure 5.2: ***The system boundaries for the assessment of the 'present situation'.***

5.4.1 Assumptions, Conditions and References

Table 5.8 gives a summary of the specific assumptions, conditions and references used for the different life cycle stages included in the current situation (2005 is the reference year). The general conditions and assumptions described in Chapter 5.1 also apply here.

Table 5.8: ***Description of the different life cycle stages for the current situation.***

Life Cycle Stages	Description of the assumptions, conditions and references used.
Extraction of coal	Not relevant for this scenario.
Transport of Coal to Norcem Brevik	Not relevant for this scenario.
Production	Clinker production at Norcem Brevik, using waste derived fuels as part of the fuel required for this. See Table 3.1 for the energy and CO2 emissions data for the fuels used [1, 2]. Data for CO_2 emissions for the waste derived fuels used at Norcem Brevik (see Table 5.1) are the provided by Norcem. These data are those used for calculation of annual CO_2 emissions for clinker production (as reported to the Norwegian Pollution Control Authority). Norcem Brevik's clinker kiln is assumed to have 100% energy efficiency (the whole energy content of the fuels burnt is used[12]) [18]
Transport of waste to Norcem Brevik	Transport of the different waste fractions to Norcem. Table 5.6 shows the data used for these transport stages of this life cycle.
Alternative treatment	Not relevant for this scenario.

Table 5.9 ***Transport data used for transport of the different wastes to Norcem.***

Waste	Distance (km, [9])	Description of the data and assumptions used.
Waste Oil	-	Local treatment assumed.
Solid hazardous waste	110	Local collection from the sources of the wastes is not included. Half of the amounts used are assumed transported from Aurskog, the rest from Brevik (0 km). European lorry 32t assumed. One way (no return transport allocated to this system).
Liquid hazardous waste		
RDF	110	50/50 from Sandvika and Vestfold. European lorry 32t assumed. One way (no return transport allocated to this system).
Sawdust	0	Assumed local source of sawdust.
CCA wood	0	Assumed that this is collected by Renor, Brevik (local).
Plastic	0	Collection and transport of plastic from households/other sources in Norway not included. Transport from Renor, Brevik to Norcem 0 km (local).
Animal meal	483	Average distance from Grødaland, Sandeid and Stranda. European lorry 16t assumed. One way (no return transport allocated to this system).

[12] LHV assumed.

6 Results

6.1 Global Warming Potential

The environmental impact category global warming potential has been analysed in this study.

Table 6.1 under shows examples of which emissions contribute to global warming potential and the potential environmental effects these can give.

Table 6.1: ***The environmental impact category global warming potential, examples of relevant emissions and potential environmental effects.***

Environmental impact category	**Example of emissions**	**GWP factor** [19]	**Potential environmental effects**
Global warming potential (global climate change/ greenhouse effect/ GWP)	CO_2 (carbon dioxide)	1	Temperature increase in the lower part of the atmosphere that can give rise to climate changes, something that can, in turn, lead to serious consequences for Earth, in the form of a changed/more extreme climate, increased desertification, raised sea levels due to glaciers melting, etc.
	CH_4 (methane)	23	
	N_2O (laughing gas)	296	
	CF_4/C_2F_6 (tetrafluoromethane, or FC-14 / hexafluoro-ethane, or HFC-116)	5700/ 11900	

The factors shown in Table 6.1 show that small amounts of a gas that has a high GWP factor (e.g. C_2F_6) can contribute much more to GWP than large amounts of CO_2.

In order to show how the different activities contribute to the total environmental impacts for the energy carrier systems analysed, the environmental impacts are presented split up into the different life cycle stages for each system.

The reader should note that the results that are presented in chapters 6.1 and 6.2 are not for the whole of Norcem's fuel use, but only for the emissions related to the amount of waste and coal described in Chapter 2. The table at the beginning of each of these results chapters explains what is included in each life cycle stage presented (see tables 6.2 - 6.4).

6.1.1 Previous Situation, heat energy recovered from waste used in Norwegian Industry.

The following life cycle stages are presented:

Table 6.2: ***Description of the different life-cycle stages presented in this chapter.***

Life-cycle stages (activity)	**Description**
Coal extraction	Extraction of coal from the earth (mining). The amount of coal extracted corresponds to the amount of coal required to deliver the same amount of energy in the clinker kiln as produced from the waste fractions burnt in 2005.
Transport of coal	Transport of the extracted coal to Norcem Brevik.
Production	Clinker production at Norcem Brevik using coal. The results shown here are for the amount of coal required to deliver the same amount of energy to the clinker kiln as was delivered by waste derived fuels in 2005. It is very important that the reader realises that the results presented are not the total emissions from production, but rather the portion of these emissions that would arise from use of coal if the waste was not burnt in the clinker kiln (see Table 2.1 and Table 5.4 for more details).
Transport of waste	Transport of the different waste fractions to alternative waste treatment (instead of Norcem Brevik).
Alt. waste management	Alternative waste management of the given waste fractions (if not to be burned at Norcem Brevik).
Avoided energy	The environmental benefits arising when heat energy recovered from producing energy at a waste incineration plant is used in Norwegian industry (see tables 5.2 and 5.4).

Figure 6.1 shows the contributions to global warming potential (GWP) in tonne CO_2-equivalents per functional unit. The GWP figure shows the contributions from the different life cycle stages (as described above).

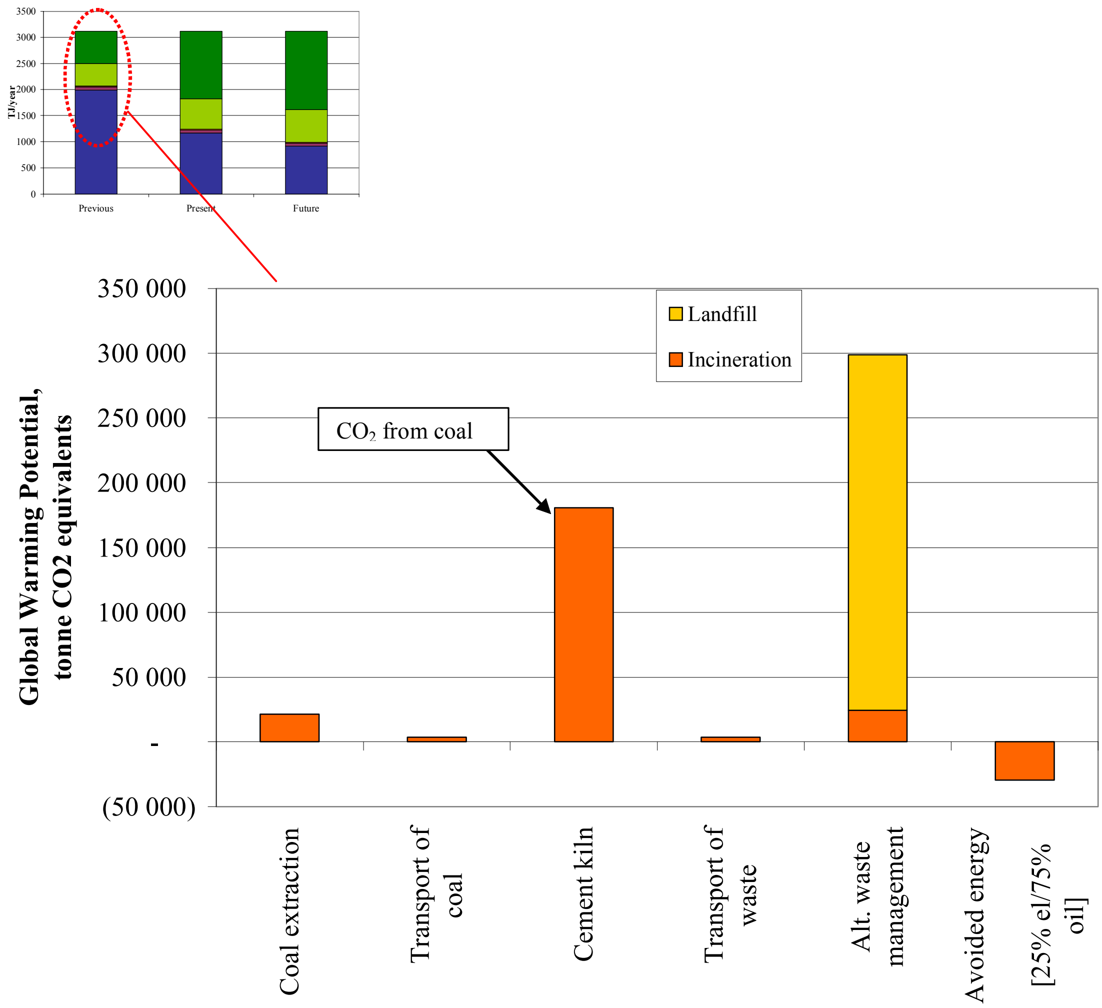


Figure 6.1: ***Global warming potential for the Previous Situation,* heat energy recovered from waste used in Norwegian industry *(tonne CO_2-equivalents / FU).***

The figure shows that the previous situation would give emissions of greenhouse gasses in both the production plant (the clinker kiln) and in the alternative waste management processes.

It can be seen that alternative waste incineration gives rise to a negative greenhouse gas emissions, as a result of 'avoided energy'. Waste incineration at municipal waste treatment plants produces energy, which is used instead of other forms of energy. Figure 6.1 also shows that the savings in greenhouse gasses achieved by incineration of waste are of the same order of magnitude as the emissions linked to the extraction of coal.

The emissions from production presented above are approximately 31 % of Norcem Brevik's total emissions of greenhouse gases in 2005.

It should be noted that the results for alternative waste management include incineration of most of the wastes, but also landfill for one of the waste fractions (RDF, see Table 5.4 for details). Decomposition of this waste in a landfill would give rise to emissions of methane (CH_4), which has a higher contribution to global warming potential than CO_2 emissions that arise from incineration (see Table 6.1).

6.1.2 Previous Situation, waste incineration at Brobekk.

The following life cycle stages are presented:

Table 6.3: ***Description of the different life-cycle stages presented in this chapter.***

Life-cycle stages (activity)	Description
Coal extraction	Extraction of coal from the earth (mining). The amount of coal extracted corresponds to the amount of coal required to deliver the same amount of energy in the clinker kiln as produced from the waste fractions burnt in 2005.
Transport of coal	Transport of the extracted coal to Norcem Brevik.
Production	Clinker production at Norcem Brevik using coal. The results shown here are for the amount of coal required to deliver the same amount of energy to the clinker kiln as was delivered by waste in 2005. It is very important that the reader realises that the results presented are not the total emissions from production, but rather the portion of these emissions that would arise from use of coal if the waste derived fuels were not used in the process (see Table 2.1 and Table 5.4 for more details).
Transport of waste	Transport of the different waste fractions to alternative waste treatment (instead of Norcem Brevik).
Alt. waste management	Alternative waste management of the given waste fractions (if not to be burned at Norcem Brevik).
Avoided energy	The environmental benefits arising when heat energy recovered from producing energy at a waste incineration plant is used to replace Norwegian average electricity (Brobekk case) (see tables 5.5 and 5.6).

In Figure 6.1, it is assumed that heat from the incineration plant is delivered to industry where it replaces energy that would have been produced from the following energy sources:

- 75 % oil-fired boiler
- 25% electricity (Norwegian mix).

If the municipal incineration delivers energy to households (district heating and/or electricity), the energy produced would replace electricity only, as at the Brobekk waste incineration plant. Figure 6.2 shows the global warming potential results with this assumption.

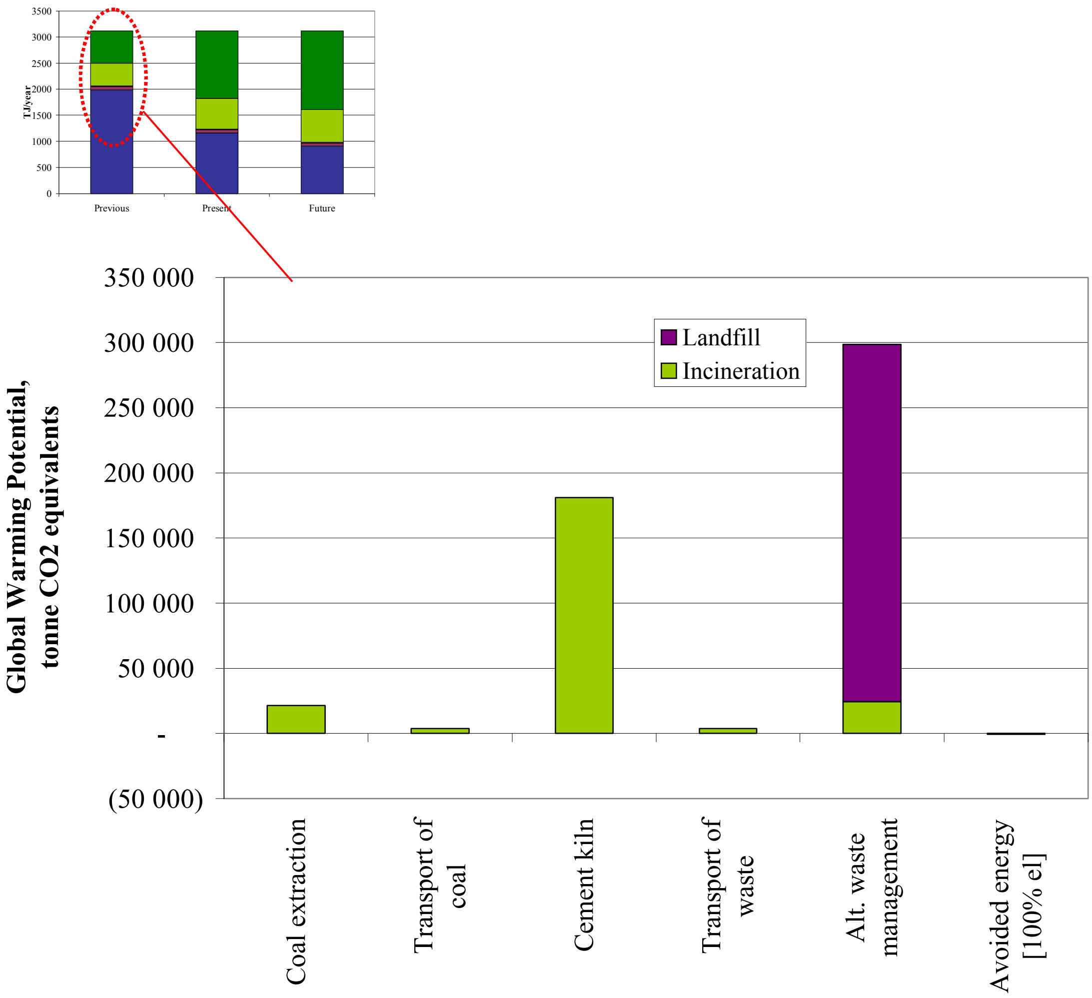


Figure 6.2: ***Global warming potential for the Previous Situation* – 100% electricity *(tonne CO_2-equivalents / FU).***

If the energy produced from waste incineration replaces the energy used in households, rather than energy use in industry, the benefits of this 'avoided energy' decrease. This illustrates how closely linked the actual 'avoided energy' is to the potential environmental benefits of energy recovery of the energy content of wastes. The 'Now Situation' results in Chapter 6.1.3 and the comparison in Chapter 6.1.4 illustrate the fact that the more 'dirty' the energy carrier replaced by waste incineration the better the environmental profile (e.g. Norwegian electricity 'avoided' in Figure 6.2 is 'cleaner' than the oil/electricity mix shown in Figure 6.1, which is in turn 'cleaner' than the coal replaced by waste in Figure 6.3).

The emissions from production presented above are approximately 31 % of Norcem Brevik's total emissions of greenhouse gases in 2005 ("previous" case).

6.1.3 Present situation, waste incineration at Norcem Brevik.

The following life cycle stages are presented:

Table 6.4: ***Description of the different life-cycle stages presented in this chapter.***

Life-cycle stages (activity)	**Description**
Production	Clinker production at Norcem Brevik using waste derived fuels. It is very important that the reader realises that the results presented are not the total emissions from production, but rather the portion of these emissions that would arise from burning the specified amount of waste in the clinker kiln (see Table 2.1).
Transport of waste	Transport of the different waste fractions to Norcem Brevik.

Figure 6.3 shows the contributions to global warming potential (GWP) in tonne CO_2-equivalents per functional unit. The GWP figure shows these contributions for the different stages in the life cycle (as described in Table 6.3).

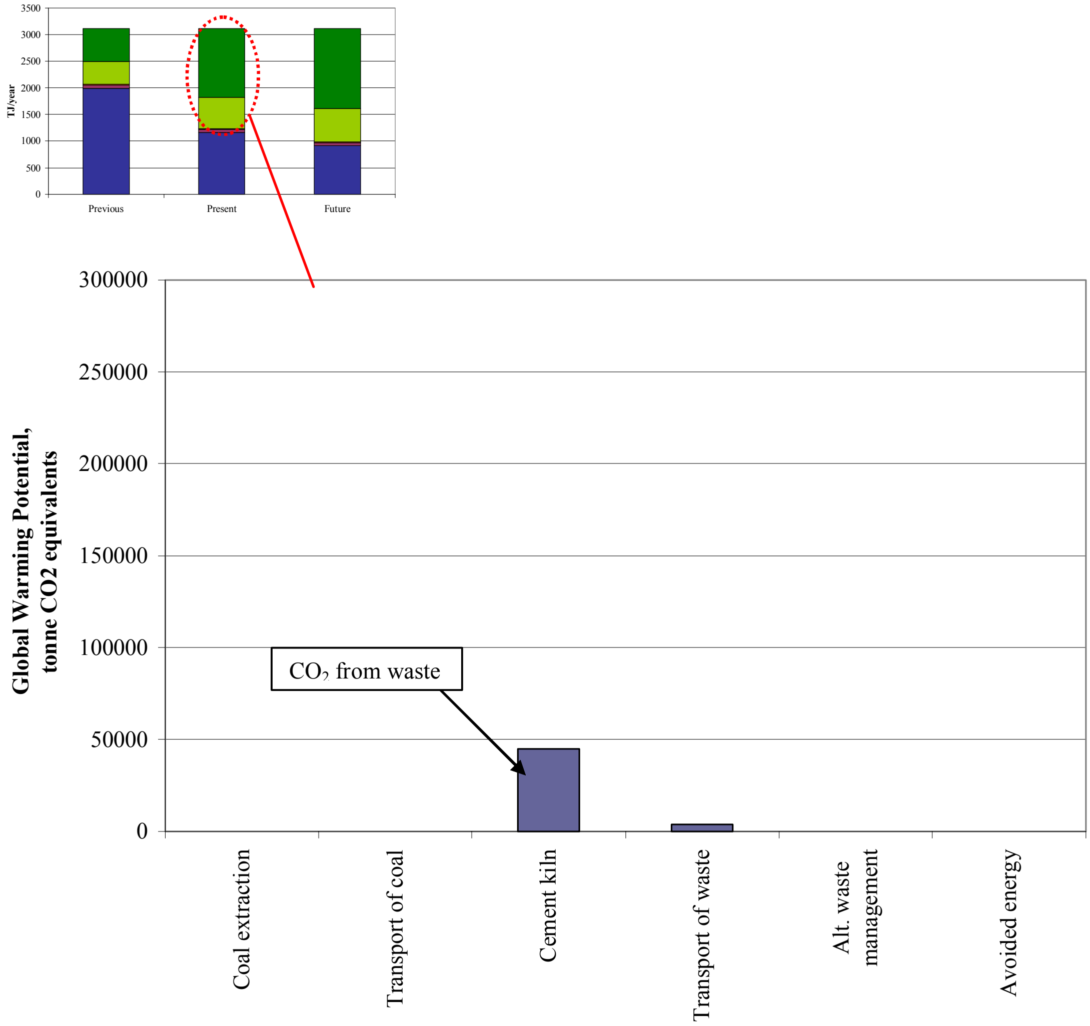


Figure 6.3: ***Global warming potential for the Present Situation (tonne CO_2-equivalents / FU).***

The emissions from production presented above are approximately 8 % of Norcem Brevik's total emissions of greenhouse gases in 2005.

6.1.4 Comparison of the systems analysed

Figure 6.4 shows the contributions to global warming potential in kg CO_2-equivalents per FU for the systems analysed.

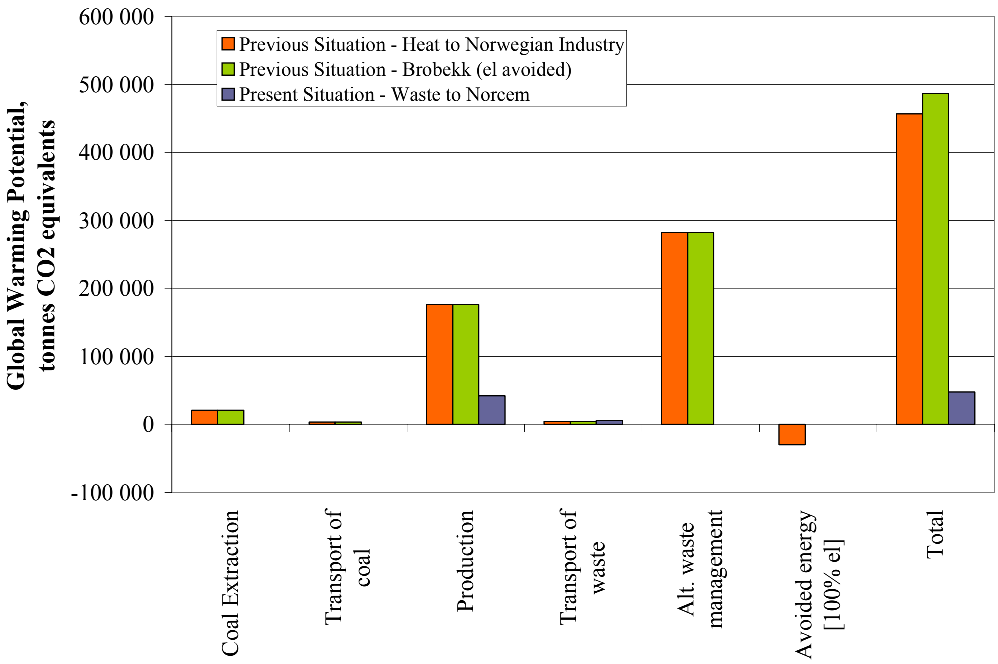


Figure 6.4: ***Comparison of the global warming potential (kg CO_2-equivalents / FU) for the systems analysed.***

This figure shows a comparison of the three scenarios presented in chapters 6.1-6.3.

The reduction in overall greenhouse gasses shown for the "Present Situation" is due to the following:

- √ no waste is sent to landfill, which means no CH_4 emissions;
- √ less extraction of coal is needed;
- √ coal is replaced with waste energy sources;
- √ there is a high content of biomass in the waste energy sources (no fossil-based CO_2 emissions).

The total reduction in greenhouse gas emissions shown in Figure 6.4 is approximately 400 000-440 000 tonnes CO_2 per functional unit.

6.2 Ash Production

Ash Production as a result of incineration of wastes in municipal incineration plants can be considerable. Reference [20, page 15] gives the following information about ash production at a NOAH waste incineration plant:

(Translated from the original Norwegian text) '*the waste products* [ash] *are expected to amount to 20-30 percent of the weight of waste input into the plant'*.

If the waste that is currently used at Norcem (120 920 tonnes in 2005) is sent to municipal incineration instead, the amount of ash that would be generated (assuming a 20-25% ash generation) would be approximately 24 000 – 30 000 tonnes. This is waste that would need to be sent to landfill. Energy recovery of this waste at Norcem means that any ash generated becomes part of the cement product. No such landfill waste is generated.

7 Discussion

Norcem Brevik's current energy sources are a mixture of different fuels. Part of the coal requirement for the clinker kiln has been replaced with alternative fuels. The alternative fuels used have also included waste derived fuels since 1994. These waste derived fuels are a mixture of fossil and biomass. This substitution has improved the emissions profile of the company compared to the time when all of the fuel requirement was provided by coal. However, if the entire alternative fuels quotient for Norcem Brevik had been filled by using biomass, the company's environmental profile would have improved even more.

Figure 7.1 shows the total global warming potential for Norcem Brevik, with the following waste treatment scenarios:

Energy scenario	Description
Waste treatment external (Norwegian industry)	Coal is incinerated at Norcem Brevik and waste is treated externally: incineration with energy recovery, where the energy produced replaces other energy sources in industry (75% light fuel oil, 25% Norwegian electricity).
Waste treatment external (Brobekk case)	Coal is incinerated at Norcem Brevik and waste is treated externally: incineration with energy recovery, where the energy produced replaces Norwegian electricity.
Waste treatment Norcem	Waste derived fuels substitute coal at Norcem Brevik.

In order to see the full potential for the use of waste at Norcem Brevik, Figure 7.1 shows the waste treatment scenarios for the following cases:

Case	Description	Amount used at Norcem Brevik		Alternative[13] waste treatment			
				Norwegian industry		Brobekk	
		Coal[14] (t)	Waste[15] (t)	Coal (t)	Waste[15] (t)	Coal (t)	Waste[15] (t)
2004	The situation at Norcem Brevik in 2004 (Previous).	69 872	67 320	36 076	67 320	36 076	67 320
2005	The situation at Norcem Brevik in 2005 (Present).	43 269	120 920	43 269	120 920	43 269	120 920
Future	The situation at Norcem Brevik in the 'future', with the maximum waste derived fuel use.	33 069	140 500	33 069	140 500	33 069	140 500
Biomass only	The situation at Norcem Brevik in the 'future', with the maximum waste derived fuel use, where all the waste derived fuels used are biomass (no fossil-based wastes, like plastics, used).	33 069	140 500 (100% biomass)	33 069	140 500	33 069	140 500

[13] These to alternative scenarios are very similar, but replace different types of energy (see the table over).
[14] This is actually fossil fuels, but due to limited space in the table and the fact that it is coal that is replaced by waste derived fuels, 'Coal' is used instead of fossil fuels.
[15] The waste composition assumed in this study is described in Table 2.1, page 7.

The table on the previous page shows the amounts of coal and waste derived fuels that are used in the different scenarios shown in Figure 7.1. The colours used in the table correspond to the colours used for the bars in Figure 7.1.

The total amount of energy required for Norcem Brevik is approximately 3120 TJ for all of the cases shown in the table above.

Figure 7.1 shows the improvements that have been made by Norcem's introduction of alternative fuels. The figure also shows the potential additional improvements Norcem could achieve if the company had not taken on the societal burden of disposing of waste. If Norcem switched to the maximum amount of waste based fuels[16] to biomass fuels they could reduce their fuel related emissions by about 9% of the future fuel emissions.

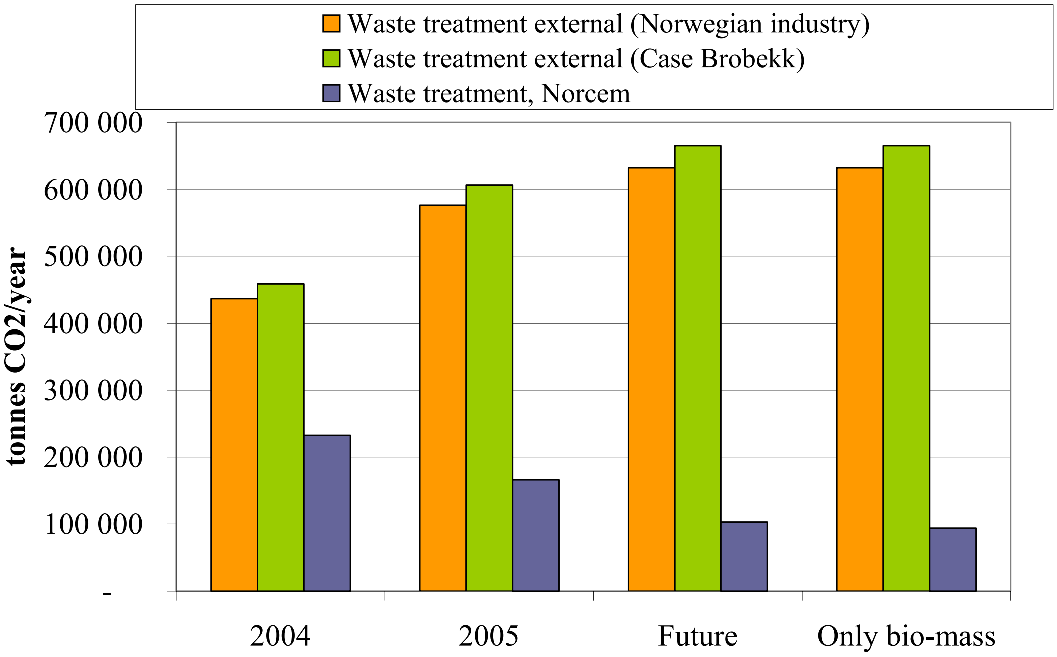


Figure 7.1: ***Greenhouse gas emissions for fuels used at Norcem Brevik (not including CO_2 emissions from the calcination process), with three different alternative fuel scenarios.***

Figure 7.1 shows that using waste derived fuels at Norcem Brevik as a substitute for coal (blue bars) avoids the potential impacts of treating the waste externally (green, or orange bars). The results for Norcem Brevik (blue) show that the increase in waste-derived fuels over time means a reduction in CO_2 emissions at Norcem Brevik. The final scenario shown in the figure ('only bio-mass') shows that if the maximum amount of coal is substituted by waste derived fuels that were derived from biomass alone, Norcem Brevik would have lower CO_2 emissions than if the current waste composition was used (including components like waste oil).

This study has not quantified all of the relevant socio-economic aspects of burning hazardous wastes at Norcem Brevik. This study has focussed on global warming

[16] With the waste derived fuels composition for 2005, shown in Table 2.1

potential (greenhouse gasses) and to a limited extent, ash production. Other relevant aspects include:

- Treatment of hazardous waste can be a source of toxic emissions. Burning such waste in a very high temperature incineration process, such as the cement kiln at Norcem Brevik, ensures the destruction of components that could form toxic emissions in the lower temperatures used in municipal waste incineration facilities (e.g. dioxins).

- Reference [20] also documents that heavy metals do not leach from cement and concrete products. This means that using hazardous wastes (high heavy metal content) for cement production is a safe way of disposing of these wastes.

8 Conclusions

The results shown in Chapter 6 and the discussion in Chapter 7, give the following conclusions:

Norcem Brevik has reduced greenhouse gas emissions by using waste derived fuels as a substitute for coal, due to the following:

- √ no waste is sent to landfill, which means no CH_4 emissions;
- √ less extraction of coal is needed;
- √ coal is replaced with waste energy sources;
- √ there is a high content of biomass in the waste energy sources (no fossil-based CO_2 emissions).

The annual reduction in greenhouse gas emissions is approximately 420 000 tonnes CO_2 per functional unit.

Incineration of waste in Norcem Brevik's cement kiln, means that any ash produced becomes part of the cement product. If municipal waste incineration was used, waste ash would need to be disposed of (approximately 13 000 - 20 000 tonnes per year).

Treatment of hazardous waste in Norcem Brevik's gives the following additional benefits:

- the cement kiln ensures the destruction of components that could form toxic emissions in the lower temperatures used in municipal waste incineration facilities (e.g. dioxins);
- heavy metals do not leach from cement and concrete products, thus using hazardous wastes (high heavy metal content) for cement production is a safe disposal route.

Norcem Brevik could experience additional improvements in emissions if the company had not taken on the societal burden of disposing of waste. If Norcem switched from waste fuels to biomass fuels they could reduce their greenhouse gas emissions from fuel use by 9% of the fuel related emissions.

9 References

1. Brevik, P., *E-mail* about LHVs and CO_2 factors for Norcem Brevik's fuels, 17/7/05.

2. Norcem A.S, *Miljørapport 2004 Norcem A.S* (Environmental Report 2004, Norcem A.S), www.norcem.no.

3. SimaPro software and databases (version 6.0.4), PRé Consultants bv, The Netherlands.

4. Lindfors, L.G., Christiansen, K., Hoffman, L., Virtanen, Y., Juntilla, V., Hanssen, O.J., Rønning, A., Ekvall, T., Finnveden, G. (1995): *Nordic Guidelines on Life Cycle Assessment*, Nordisk Ministerråd, Nord 1995:20.

5. IEA Statistics, *Electricity Information 2004 (with 2003 data)*, OECD/IEA, 2004.

6. Askham, C., Vold, M., Rønning, R., *Life Cycle Inventory of Norwegian Energy Carriers, Oil and Gas*, Østfold Research Foundation, OR.52.98.

7. EcoInvent database v1.1 (2005): www.ecoinvent.ch, ETH (Swiss Centre for Life Cycle Inventories).

8. http://www.webflyer.com/travel/milemarker/

9. http://www.viamichelin.com/viamichelin/gbr/dyn/controller/ItiWGHomePage?

10. SFT (1999): *Naturressurser og miljø 1998*.

11. Raadal, H. L., Nyland, C. A., (2003): *Vurdering av kildesortering og gjenvinning av plastemballasje- avfall med Optibag-system for SHMIL* (Assessment of source sorting and recycling of plastic packaging waste with the Optibag system for SHMIL), Østfold Research Foundation, OR.27.03.

12. Raadal, H. L., Nyland, C. A., (2003): *Vurdering av kildesortering og gjenvinning av plastemballasje- avfall med Optibag-system for HAF* (Assessment of source sorting and recycling of plastic packaging waste with the Optibag system for HAF), Østfold Research Foundation, OR.26.03.

13. Raadal, H. L., Hanssen, O. J., Nyland, C. A., (2003): *Vurdering av foreslåtte virkemidler for materialgjenvinning og energiutnyttelse av tre avfallsfraksjoner* (Assessment of proposed measures for material recycling and energy recovery of three waste fractions), Østfold Research Foundation, OR 20.03.

14. Raadal, H. L., Nyland, C. A., Hanssen, O. J., (2003): *Sammenligning av kjemisk gjenvinning, mekanisk gjenvinning og forbrenning av husholdningsplast* (versjon II), (Comparison of feedstock recycling, mechanical recycling and incineration of household plastic packaging waste, version II), Østfold Research Foundation, OR 12.03.

15. Sandgren, J., Heie, A., Sverud, T. (1996): *Utslipp ved håndtering av kommunalt avfall*, SFT 96:16.

16. Frøiland Jensen, J.E., Williksen, T., Bartnes, J. (1999): *Beregningsmodell for utslipp av metangass fra norske deponier* (Calculation model for emissions of methane gas from Norwegian landfills), SFT 99:16.

17. http://www.ssb.no/emner/01/04/10/klimagassn/arkiv/art-2005-02-09-01.html and telephone discussions about methodology for calculation of CH_4 and CO_2 emissions from landfill (contact with: Jens Erling Frøland Jensen and Torkil Williksen, SFT).

18. Tokheim, Lars-André, *Phone* about LHVs, efficency of own and CO_2 factors for Norcem Brevik's coal, pet-coke and diesel, July 2005,

19. *CML Baseline 2000 v 2.03*, CML, The Netherlands, 2000.

20. Moxnes E. (1994): *Forbrenning av spesialavfall: En samfunnsøkonomisk analyse av to alternativ* (Incineration of hazardous waste: a socio-economic analysis of two alternatives), Stiftelsen for samfunns- og næringslivsforskning, SNF-rapport 64/94

21. http://www.miljostatus.no/templates/status____5159.aspx (CO_2 emissions Norway 2003) og http://www.ssb.no/emner/02/02/folkendrhistlf/tab-2005-06-09-01.html (population statistics for Norway 2003)

22. http://www.ssb.no/emner/02/01/10/beftett/tab-2005-06-03-01.html

23. Bang J. et al., *Utslipp fra veitrafikk i Norge* (Emissions from road transport in Norway, SFT 99:04.

24. http://www.bbc.co.uk/science/space/solarsystem/earth/index.shtml# (facts and figures link about the Earth).

10 Appendices

Appendix 9.1: Life Cycle Assessment (LCA) – Methodology

1. What is a Life Cycle Assessment (LCA) ?

"A process that evaluates the environmental burdens associated with a product system or activity." This is done by identifying and describing the energy and material uses and releases into the environment. An LCA includes the entire life cycle of the product, from raw material extraction, through materials processing, use and disposal at the end of the product's life (from "cradle to grave"). All transportation steps involved are also considered. LCA assesses the environmental impacts of the system in the areas of ecological systems, human health and resource depletion. It does not address economic or social effects.

2. Why Life Cycle Assessments?

Life cycle assessments give a more holistic approach to environmental aspects of products. They can help the producer understand much more about what environmental problems are associated with a product. The producer can also see where in the product life cycle the main environmental burdens arise. This is very useful information when deciding where to target resources for environmental improvements, so that the resources will be used most effectively.
There are many more uses for LCA, including analysing the results of future changes in production, or raw materials suppliers etc. A short summary of the main applications is given below:

Knowledge development

- What are the most important environmental problems and where in the life cycle do these arise?
- What happens to our environmental profile if we make changes in our production process?

Decision support

- Where are the most effective areas for us to target resources (personnel, technology, education) to improve our performance?
- What sort of product/marketing profile do we want?
- Which materials and suppliers should we use?

Information exchange/ communication

- Information for employees (internal stakeholders), education as well as key environmental data (EPIs) and environmental product information (EPDs).
- Communication of the effects of a company's environmental improvement efforts to authorities, neighbours, finiancial institutions and external stakeholders (EPIs)

3. The phases of an LCA

According to the ISO 14040 standard, life cycle assessments shall include:

1. Goal and scope
2. Inventory analysis
3. Impact assessment
4. Interpretation of results

3.1 Goal and Scope

Goal

The goal of an LCA study should state the intended application, the reasons for carrying out the study and the intended audience, i.e. to whom the results of the study are intended to be communicated.

Scope

When defining the scope of an LCA study, the following items should be considered, clearly described and justified:

- The functions of the product system, or, in the case of comparative studies, the systems
- The functional unit
- The product system to be studied
- The product system boundaries
- Allocation procedures
- The types of impacts and the methodology of impact assessment and subsequent interpretation to be used
- Data requirements
- Assumptions
- Limitations
- The initial data quality requirements
- The type of critical review, if any
- The type and format of the report required for the study

Functional Unit

The functional unit represents a product's performance according to a specific user's requirements. This unit should reflect the product's function and life span.

Here is an example of a functional unit for cement and concrete:

1 km road, maintained and used over a 50 year lifetime

It is important that 'used' is included, as it is nescessary to include other important aspects in the life cycle of the road. These are things like lighting, noise muffling, road markings etc.

In an LCA, all mass and energy flows are normalised according to the functional unit. Therefore all results are usually presented for the functional unit chosen.

System Boundaries
System boundaries must be defined, so that we can collect the right inventory data. When one sets system boundaries one defines to what level of detail the product system will be studied and which releases to the environment will be evaluated. It is important that decisions to omit life cycle stages, processes or data are clearly stated and justified.

Available inventory data can also set limitations to data gathering (for example when only industry average data is available rather than site specific). Again these limitations must be clearly stated and taken into consideration when conclusions are drawn from the LCA study.

In order to help define system boundaries a process tree is drawn. This process tree should include all life cycle stages and unit processes involved, including transportation. The functional unit is the basis for which the product tree is drawn. Chapter 4.1 gives an example of a product tree. The Product trees for the systems analysed in this study are given in chapters 5.2-5.8.

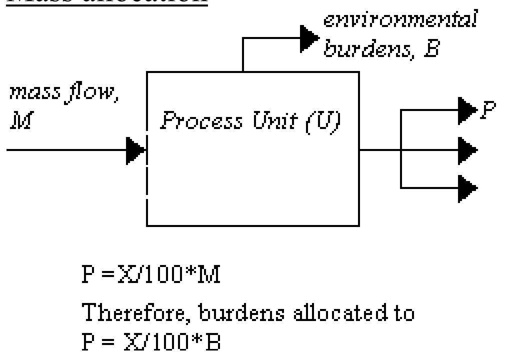
When defining the system boundaries one must be practical, otherwise the level of detail can be enormous. A common approach is to define cut-off criteria, for example that all components that contribute less than 1% of the total mass flow for the product system are not included.

Other important system boundaries that should be clearly stated are geographical boundaries (e.g. is the study of a local, national, or international nature) and time (e.g. what is the reference year for which the data is collected). The intended application of the study, the assumptions made, cut-off criteria, data and cost constraints and the intended audience all affect the system boundaries. This makes it important that these aspects are documented clearly.

Allocation procedures
Allocation is the partitioning of the input or output flows of a unit process to the product system under study. Allocation is needed when a unit process in a product's life cycle has more than one product or raw material, which is part of another life cycle. This means that it is not correct to allocate all environmental burdens from the unit process to just one of the products.

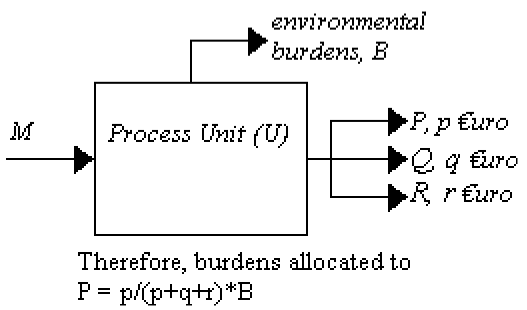
There are several possible methods that can be used for allocation. The two methods that are most commonly used are mass allocation and economic allocation, but others such as volume and energy-based allocations can be used where appropriate.

Mass allocation



Mass allocation is based on the mass flows through the unit process and is illustrated in the diagram above. The percentage (X) of a given flow (M), contributing to a given product (P), through a given unit (U) has been calculated. This same percentage (X) is then used as the percentage of the environmental burdens (B) arising from the unit which are allocated to the product (P). Thus, if a product uses 37% of the mass flow, it's also assigned 37% of the environmental burdens.

Economic allocation



Economic allocation is based on the sales price of the products produced and is illustrated in the diagram above. Products P, Q and R are produced from the unit process (U). Their sales prices are p, q and r respectively. Product P is therefore allocated the fraction p/(p+q+r) of the environmental burdens (B) arising from the process unit. Thus, if the sales price of product Q is 40% of the total sales price, it's assigned 40% of the environmental burdens.

Assumptions
It is important for the interpretation and use of the results from an LCA that all assumptions are clearly documented. The assumptions and system boundaries used affect the applicability of the results.

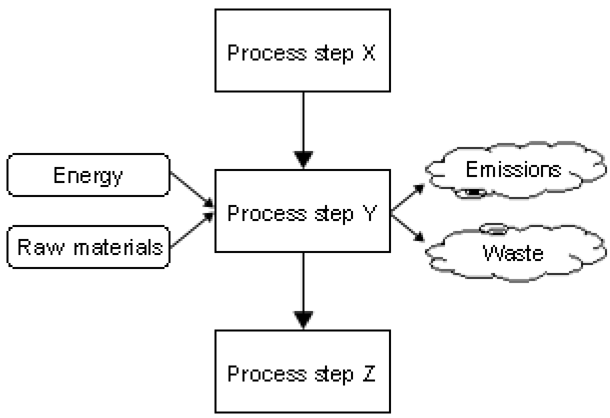
The assumptions used can be tested to see whether changing these assumptions within reasonable intervals can change the conclusions of the study. This is known as a sensitivity analysis and enables the LCA practitioner to gain an understanding of the robustness of the conclusions from the particular study.

Limitations
There are also only a certain number of environmental burdens examined in an LCA study. This means that although LCA is described as a holistic approach it is also limited to the particular environmental burdens described in the scope definition for the study.

LCA assesses the environmental impacts of the system in the areas of ecological systems, human health and resource depletion. It does not address economic, or social effects.

3.2 Inventory Analysis

Inventory analysis is the step where all material and energy flows in and out of the product life cycle are quantified. It involves data collection and calculation procedures to quantify the relevant inputs and outputs of a product system. Thus inventory analysis aims to quantify all energy and raw material requirements, emissions to air, discharges to water, solid waste and other releases for each process step of a product system.



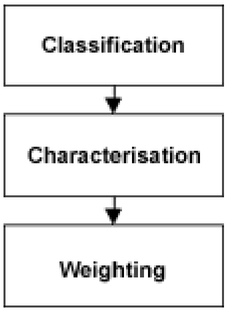
All inputs and outputs to the product system are related to a functional unit, which is the basis for the calculations performed. For example we don't make an inventory of what emissions and resource use are associated with a tonne of concrete, but for the amount of concrete required for the maintenance and use of a 1 km stretch of road over a 50 year lifetime.

When the inventory analysis is complete you have the life cycle inventory (LCI) data.

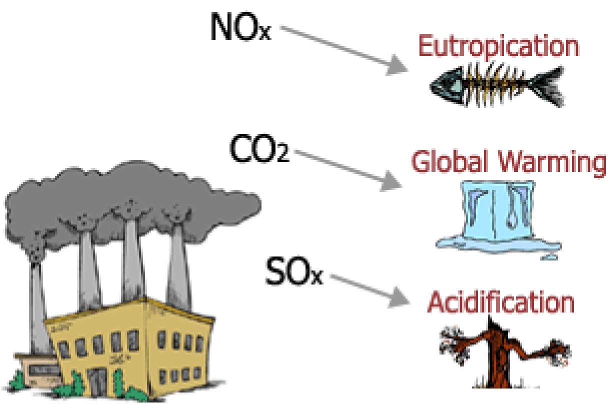
3.3 Impact Assessment

Different environmental problems occur as a result of the fact that we extract and process raw materials to produce different products. Different emissions contribute to different environmental problems (environmental impacts) in different ways.

The impact assessment part of an LCA is where the potential impacts of a life cycle are assessed. The results of the inventory analysis (LCI) are used as the basis for this. The impact assessment is formally described as including the three phases shown in the figure below.



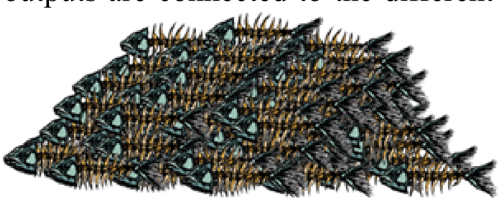
Classification - *"Which emissions contribute to which impact categories?"*



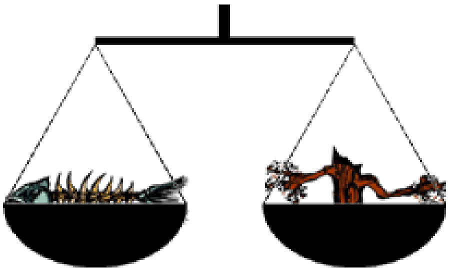
In the classification step, the different emissions and energy demands are assigned to different impact categories based on the expected kind of impacts on the environment. The main purpose of the activity is to describe which potential environmental effects the inputs and outputs may cause.

Characterisation - *"How much do they contribute?"*

In the characterisation step, the potential contributions from the different inputs and outputs are connected to the different impact categories, and the contributions to the same impact category are added up. Different emissions contribute differently to a given impact category, e.g. methane (CH_4) contributes 21 times more to global warming potential than carbon dioxide (CO_2).



Weighting - *" Which impacts are most important?"*



The weighting phase is an optional phase (ISO 14043, 1999) where the results for each impact category are weighted into an overall quantitative statement of the potential environmental impact for the product system.

3.4 Interpretation

In this phase of an LCA one analyses results, reaches conclusions, explains limitations and makes recommendations. It is important that one considers carefully the goal and scope of the study during this phase. Interpretation of the results of an LCA must be done according to the Goal and Scope of the study in order to be of value in decision-making.

A good example of this is if data gaps in the inventory phase are shown to be important for the outcome of the study, one recommendation would be to repeat the LCA calculations and fill in the most important data gaps.