Product Quality and Sustainability in the Cement Industry

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Abstract
Sustainability is of great concern to the cement industry with the main issues being the emission of carbon dioxide and the continuously increasing global demand for cement. Sustainability is about making best use of resources – creating maximal value compared to environmental effects. Sustainability can be measured using the Triple Bottom Line, which measures performance in the economic, environmental and social dimensions. Value created for the customer should form part of the economic dimension. This value should relate both to the price of cement and to the environmental effects. By creating specific indicators such as value per price and value per emissions we are able to define best practice benchmarks and to use these to evaluate the existing improvement potential. Results show that the cement industry generally has a considerable potential for improvement. Some part of this potential could be realized relatively easily with an increased focus on process improvement and variability reduction.

1 Introduction

The World Commission on Environment and Development (WCED), [1], launched the now commonly used definition for sustainable development as: "Sustainable development is development that meets the needs of the present generation, without compromising the ability of future generations to meet their own needs". Organizations now play an important role in global sustainability, with many economically dwarfing nations. On a list of the world's 100 largest economic entities there are more organizations than nations. With this change there are growing expectations for businesses to perform in a sustainable manner and to demonstrate this by reporting Triple Bottom Line (TBL) performance in the economic, environmental and social dimensions. The TBL is based on the understanding that good economic performance is required for environmental and social progress, and this approach has been adopted by the Cement Sustainability Initiative program of the World Business Council for Sustainable Development (WBCSD).

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change has identified that global warming and its effects are almost certainly attributable to emissions of greenhouse gases, such as carbon dioxide. The global cement industry is currently responsible for about 5% of the man made CO_2 emissions and with production rates projected to

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increase significantly, these emissions are becoming an important issue for the industry. On the other hand, concrete is the most commonly used building material in the world and it is an essential component of development in most countries. Additionally the building industry is a major employer worldwide, so all dimensions of the TBL are important for the cement industry.

1.1 Review of existing sustainability indicators

An important change in the interpretation of sustainability is a widening of the focus from shareholders and customers to all stakeholders, who can be defined as: “Any identifiable group or individual who can affect the achievement of an organization’s objectives or who is affected by the achievement of an organization’s objectives”, [2]. Characteristic TBL-indicators, as expressed in the widely used Global Reporting Initiative (GRI) guidelines are such as:

- Economy – Economic value generated and distributed
- Environment – Emissions, energy and resource consumption
- Social responsibility – Labour practises and decent work, human rights, society and product responsibility

1.2 Additional indicators

As making the best use of resources is an important aspect of sustainability, then maximizing the ratio of cement performance to environmental harm should also be an objective. Customers are a vital stakeholder because they finance the business, and with limited resources, it is essential that customer needs are satisfied with the lowest resource consumption and lowest environmental impact. It could be argued that value for price is an ethical indicator, especially in poorer countries. Based on this perspective the GRI definitions could be extended to incorporate customer focus into the TBL indicators, and the following additional indicators are proposed:

- Economy - Customer value produced
- Environment - Customer value produced relative to environmental harm
- Ethics or social responsibility – Customer value produced relative to price

2. Proposed TBL indicators for cement manufacture

With the inclusion of customer value, the TBL indicators have been modified for performance assessment in the economic, environmental and ethical dimensions.

2.1 Economic performance

The economic value generated and distributed through the community is the primary concern of shareholders, employees and society, as reasonable economic performance allows the environmental and social elements of the TBL to be realised. However, customers are primarily interested in the product value, which for cement can be most conveniently expressed as compressive strength in concrete. However, as cement production quality is normally monitored and controlled by most cement producers using cement and sand mixes, the compressive strength referred to hereafter is the mortar strength measured according to the relevant testing standards. While this does not take into account the, contentious relationship between mortar, water demand and concrete strength in final use, in this context it is nonetheless considered a suitable index for broadly comparing relative product performance.

Compressive strength is the most commonly used parameter for assessing cement quality because it reflects most of the important product properties, with higher compressive strength levels usually equating to better performance and higher product value for the customer. This is somewhat of a simplification because the optimal cement characteristics depend on the application, but competent customers can usually produce more concrete from cement with a higher potential compressive strength. In addition to having reasonable average compressive strength, cement should also have predictable performance. Cement with more uniform strength can be used at lower addition rates to achieve a given performance level in the final product. This contributes to sustainability because more concrete can be made from a given quantity of cement and the CO_2 emissions generated. Lower product strength variation, expressed in terms of standard deviation, also allows cement to be produced at a lower average strength yet still comply with the required strength target expressed as the L value (see formula under section 4.4).

The European Cement standard EN 197-1 recognises this relationship when assessing product compliance. Product with a higher standard deviation must have a higher average compressive strength level to assure at least 95% of the product will meet the specified lower performance limit or L_{min} value. Because of this relationship, the actual product strength, here called L_{actual} , can be used as a direct measure of the cement va lue. Improvement work which reduces cement variation increases L_{actual} and also usually reduces process variation, which in most cases equates directly to increased specific capacity and lower costs. This also offers significant improvement to value per harm and value per price performance, which benefits multiple stakeholders. Consequently it is considered that the L_{actual} value for 28 day compressive strength is a useful indicator for product performance assessment, especially when combined with the production output. This index, measured in compound units such as MPa*tons, can be used to express the total customer value of a given product stream.

2.2 Environmental performance

It is generally agreed that the most serious environmental problem for the cement industry is the emission of CO_2, which for Ordinary Portland Cement (OPC) is typically above 800 kg CO_2/ton of clinker, when fuel and calcination are taken into account. If the WBCSD definition of Eco Efficiency of “creating more value with less impact” is considered, then the performance of the resulting cement should also be considered with respect to the emissions generated. Ideally this would mean relating emissions to the final end product or utilization, such as provision of a given amount of housing, but as the usage cannot be controlled or defined, the ratio of product value to harm is most conveniently expressed in terms of the index L_{actual} /ton CO_2 emitted per ton of cement.

2.3 Social or ethical performance

For the customer the main concern is having as much value as possible for the price paid, and this indicator could be defined as the ratio of the compressive strength, L_{actual}, to the cement price, taken for convenience in US$. This results in an index of L_{actual} /US$ per ton of cement.

2.4 Benchmarks for the proposed indices

As a benchmark value, Ordinary Portland Cement (OPC) produced in an average state -of-the-art process using only clinker, gypsum and 5% mineral addition could be expected to give an average compressive strength of ~ 63 MPa at 28 days. With a stable process and state of the art testing the product variability will be low, which should allow an L value of ~60 MPa to be achieved.

An approximate benchmark value of the CO_2 emission for a typical OPC using 5% mineral addition and 5% gypsum from a state of the art process could be assumed to be ~ 0.72 tons CO_2 per ton of cement, based on clinker produced at an energy consumption of 750 kcal/kg or 3.14 GJ/ton. When expressed as the ratio of value to harm using the above values, the ratio becomes 60 MPa*tons/0.72 tons CO_2 or 83 MPa*tons/ ton CO_2. It has to be noted that cement strength and emissions can also be affected by other influences such as clinker chemistry or cement particle size effects, but these impacts are considered relatively minor and have not been factored into the presented calculations to simplify the comparison.

Setting an acceptable cement price level is always contentious, but in our examples we will use a benchmark product price of 63 US$/ton. This figure is based on product prices from countries with benchmark performance levels, and although cements are available at lower prices, we consider the long-term economic sustainability of these prices to be questionable, [4]. Combining the benchmark for the L value of 60 MPa with the price benchmark 63 US$ per ton gives a value/price benchmark of 0.95 MPa/US$*ton.

2.5 Sources of variability

Process variations contribute to fluctuations in product quality and performance parameters such as output, energy consumption and emissions. The clinker burning process is the main driver for both quality and emissions, and for best performance a kiln needs stable inputs of both kiln feed and fuel. A common rule of thumb for reasonable performance is that all inputs, based on hourly measurements, should not vary more than +/-1 percent in quality and quantity over 24 hours. However, current strategies for reducing costs and CO_2-emissions also focus on the use of substitute raw materials and fuels, and increasing the number of material inputs also increases system complexity. Unless concerted actions are taken to improve the homogeneity of the substitute materials and fuels, the variations in these material and fuels can have a severe effect on all aspects of kiln operation. In some cases this variation results in output reductions of 10 to 15%, with consequent increases in the specific energy consumption and emissions, together with increased product variation. This is exceedingly detrimental to sustainability when product performance goes down and environmental impact goes up.

An additional source of variability comes indirectly from the different cement classes which may be produced according to the various standards. For example, in the EN-system there are three strength classes; 3 2.5, 42.5 and 52.5, where the figures indicate the minimum compressive strength in MPa at 28 days. Each class has a 20 MPa range, with different producers often choosing different targets. Matters are also complicated by the use of different international standards, some of which allow production of cements with minimum 28 day strengths as low as 25 MPa. This means that cement is often produced with strength averages ranging from 30 to more than 60 MPa at 28 days, along with correspondingly variable CO_2 emi ssions. However, comparing the true effectiveness of these cements in a sustainability context becomes more practicable if product performance is expressed in conjunction with CO_2 emissions.

3 Research questions and methodology

The study behind this paper was conducted with several aims:

- to assess the focus on sustainability in the cement industry;
- to review if strategies for reducing CO_2 emissions also include a focus on variability reduction:
- to check if the indicators proposed, or something similar, is being used;

- to assess the improvement potential for the industry based on the proposed indicators at both the plant and global level;
- to look at the effect of strength testing variability on the proposed performance indicators.

To check the values and strategies for sustainable development, the sustainability reports of Industry leaders including Cemex, Holcim, Lafarge and others have been reviewed. Corroborative information on the Cement Sustainability Initiative (CSI) found on the WBCSD web-site, [5], was also studied.

4. Results

4.1 Review of industry leaders

The leading cement companies are now all reporting extensively on Triple Bottom Line performance using the Global Reporting Initiative (GRI) guidelines. Considerable care has gone into highlighting stakeholder value and identifying sustainability indicators in these reports, especially those associated with emission mitigation. Much of the earlier reporting has been environmentally focused, especially on emission abatement and use of alternative fuels and raw materials, although this is now broadening somewhat to include more reporting on social performance. Values of sustainability based on the Triple Bottom Line are now more commonly expressed in reports signed by the CEO. However, indicators regarding customer value are not apparent in the sustainability reports.

CO_2 emissions are widely used by the cement industry as a principle indicator of environmental harm, and these figures are reported by the leading cement manufacturers on their web sites, see Figure 1.

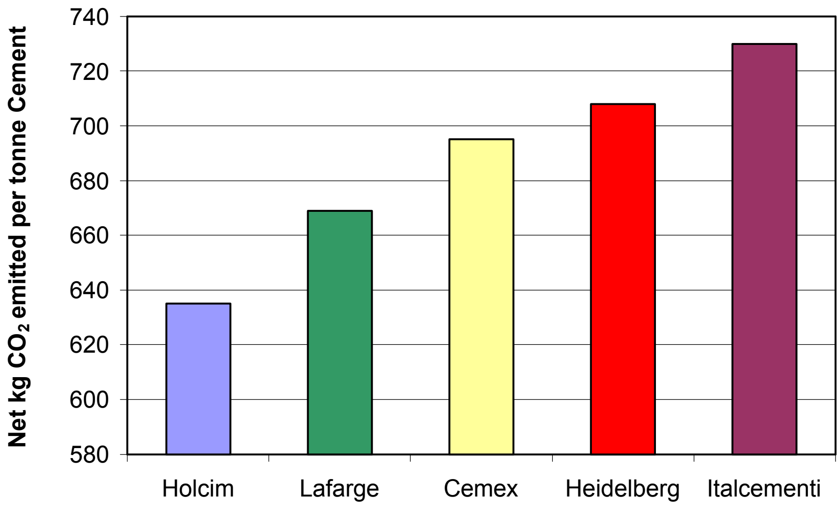

Figure 1 - Net CO_2 emissions per ton of cement as reported for 2005 on company web sites

Eco-efficiency is mentioned by many of the cement company reports and the value added is also discussed, but not in the sense that strength performance is related to CO_2 emissions, or to the price of the cement.

The most common strategies for reducing CO_2 emissions mentioned by the studied companies were noted as:

- replacing carbonated raw materials with already decarbonated materials;
- replacing fuels (using alternative fuels, notably biomass);
- improving energy efficiency by modernizing plants and processes;
- using clinker additives (slag, fly ash, limestone, pozzolans, etc).

Although some of the process and product effects of alternative fuels and raw materials are identified in the CSI publications, no specific mention was found on the effects of any of these strategies on process or product variability, which could be expected to be a significant issue, especially when using a wide variety of alternative fuels and materials. There are obvious economic benefits in using alternative fuels, but for other than direct replacement of fossil fuels, it is difficult to find much information on how this has reduced the emissions of CO_2/ton of product. The level of biomass substitution, which is the most effective replacement strategy, is reported by the three major companies to be quite low, at 1-3%. When process improvement is mentioned, this seems to relate primarily to equipment upgrading and process conversion rather than variability reduction, which implies that the processes are already running optimally, or at least are perceived as doing so.

All of the above strategies for CO_2 reduction are valid, but must be acknowledged with the comment that it is also important to understand the effects on process and product variability. When variability increases, this has a negative effect on sustainability, the magnitude of which can be gauged by maintaining a focus on the indicators of value to harm and value to price.

4.2 Review of improvement potential on a global level

In order to test and demonstrate the usability of the proposed indicators a global improvement potential has been assessed. However, as complete data sets were not available for all indicators some minor assumptions have been made which should not compromise the estimated improvement potential.

The reference product used is OPC, based on a clinker factor of 0.9, with 5% mineral additive and 5% gypsum. Based on recent figures and projected growth, a global cement consumption of 2000 Mtons has been assumed. The estimated actual and benchmark values are presented in Table 1.

Table 1 – Benchmark values and estimated actual performance

Indicator	Bench-mark	Actual	Comments
Ton CO_2/ton clinker	0.8	1	eg Cemex 0.82, Uniland 0.98
L (MPa)	60	45	Actual ranging from 30-60 MPa
Clinker fraction	0.90	0.85	Assumed for actual
Ton CO_2/ton cement	0.72	0.85	Calculated from values above Lafarge 0.67, Uniland 0.82
Price/ton US$	63	82	Assessed from surveys
MPa/US$*ton	0.95	0.55	Calculated from the above values
MPa/ton CO_2	83	53	Calculated from the above values

These results show that there is a significant improvement potential calculated as performance of strength per price and strength per emissions. If a fixed level of building need is assumed, then the maximal improvement potential can be calculated. As noted previously, with stronger cement, less is consumed with reduced environmental effects. In Table 2 the actual situation and the best case are compared.

Table 2 – Actual and best case scenarios for a fixed level of building need

	Cement Mtons	Price BiO US$	CO_2 Mtons	Comments
Actual	2000	164	1700	Assessed values
Benchmark	1500	95	1100	Based on equivalent MPa*tons
Difference	-500	-70	-600	
Difference in %	-25%	-42%	-36%	

The estimated differences from Table 1 show the importance of taking into account the value of the cement produced and relating it to CO_2 emissions.

In poorer countries where money is the limiting factor, cement consumption will increase with cheaper cement. This means that in such situations we would probably not see any reduction in the total tonnage produced. Assuming a fixed tonnage at 2000 Mtons produced at benchmark values, the effects on the TBL would be that the value in MPa*ton would increase, as would the value per harm and value per price.

The total CO_2 emissions would be reduced, but less than that indicated in Table 2. The theoretical improvement potential is important, but the principal issue in this paper is to study how much of the improvement potential is due to process and product variability.

4.3 Review of improvement potential at plant level

In order to demonstrate the validity of the proposed indicators, actual data from a number of diverse plants has been used. These results, shown in Table 3, indicate that there could be a substantial improvement potential within the existing production systems. This can be more clearly seen when the proposed indicators relating to value are applied. In all of the plants studied, irrespective of the process type, there is considerable improvement potential. Even the best performing plant in this sample had some significant unrealised improvement potential, equivalent to ~20% in value per emissions, with a possible performance of up to ~90 MPa/ton CO_2. This, it should be noted, is actually above the benchmark value of 85 MPa/ton CO_2 that was assumed earlier. Most of the plants studied here are from companies which are part of the Cement Sustainability Initiative.

Table 3 – Recorded values from selected plants expressed in L value per price and L value per CO_2 emissions.

Plant	Value/price L MPa/ US$*ton	Value/harm L MPa/ CO_2	Comments
Wet Third World	0.23	20	Average of two plants;
Dry Third World	0.38	38	Average of four plants
Dry First World	0.58	57	Average of three plants
Benchmark – wet estimated	0.7	44	Higher energy costs drive price and CO_2 emissions
Benchmark dry	0.95	83	As defined earlier

Even though there are only 9 plants in this study the results give an indication of the impact of variability and non optimal performance on the proposed indicators. In all of the cases studied – all from different countries - there was a significant improvement potential that could have been realised through variability reduction, often at a relatively low cost. The improvement potential in the studied Third World plants was more than 50% and in the First World plants in the region of 20-40%. The global average potential could be lower, but would probably still be in the range of 15 to 30%. This potential is partly due to process variation, increasing emissions and energy consumption, and partly due to cement strength variability.

4.4 Sustainability and cement strength testing

Does cement strength testing really play a role in sustainability? We can use the L_{actual} value to demonstrate that this is the case. The formula for calculating the lower acceptability limit, L_{min} is:

$$L_{min} = \text{average strength} - kA*sd \ ,$$

where the acceptability constant (kA) is a function of n (the number of yearly dispatch samples) and the chosen confidence interval (P_k).
With 70 samples and a P_k of 5%, a kA value of ~2.0 can be assumed. This means that if the cement strength standard deviation is 2.0 MPa, then the L_{actual} value must be at least 2*2.0 or 4.0 MPa above L_{min} for the cement to comply with standard requirements.

In the study of companies presented in Table 3, the sd in cement dispatch samples varied between 1.5 and 4.0 MPa. A global average sd of 2.2 MPa is assumed as an educated guess based on the findings. In order to assess the improvement potential we need a further benchmark for the annual sd for the 28 day strength on dispatch cement, which is set to be 1.2 MPa. The difference between the two values is 1.0 MPa, which means that we could potentially improve our L_{actual} value by 2.0 MPa, by reducing product variation. This may not seem much, but for cement with an L value of 45 MPa, as presented in Table 2, it would directly increase the value for price and decrease the value for harm by 4%. In global terms, customers would receive an additional product value of 6 billion US$ along with equivalent performance in the final product and an emission reduction of about 70 million tons of CO_2.

The recorded variation consists of two main parts; the cement variation and the testing variation. With regard to the testing variation, t he EN standard requirement, [6], indicates that 3.5% can be considered as the maximum allowable long-term repeatability (same laboratory, same equipment, same operator) and 4% as reproducibility (different laboratories, different equipment and different operators) when calculated as the coefficient of variation on the same cement. At a compressive strength level of 50 MPa, corresponding to the L value of 45 MPa in Table 1, this translates to a maximum allowable standard deviation of 1.8 MPa for in-house testing and 2.0 MPa when measured between laboratories. We have assumed an average global testing sd to be 1.5 MPa.

World class cement testing can do much better than the minimum requirements indicated in the standard. With due care, a competent laboratory testing a weekly reference cement to the EN197 standard should be capable of achieving a standard deviation for 28d strength measured over a year of no more than 0.7 MPa. If the dispatch benchmark cement with an sd of 1.2 MPa is used as the baseline case the difference between the actual and improved optimum situation, based on the variance (V) = s^2 , could be calculated (cement variation is calculated based on the known testing variation and the assessed dispatch variation):

$$V_{dispatch} = V_{cement} + V_{testing}$$

$$V_{actual} = 2.55 + 2.25 = 4.8; \quad sd = 2.2$$

$$V_{improved} = 0.91 + 0.49 = 1.4, \quad sd = 1.2$$

In this example almost half of the variance for the actual situation comes from testing, which means that half of the potential for reducing strength variability identified previously also comes from the testing.

The situation is further worsened by drift of the average strength, which increases with the sd. One could argue that a varying average because of testing does not matter, as the cement in actuality stays the same, but this is only the case if no actions are taken to correct the changing values, or the process remains free of process tampering. However, these adjustments seem to be the rule rather than the exception and in the real world reactions are usually swift when strengths apparently change, with alterations to additive levels or fineness to modify the strength. If the reason for the variation in the first instance is a strength testing problem or some random cause, then the overall effect is that the total variability of cement is increased. The result is that average strength must be kept at higher levels to make sure that L_{min} is met, resulting in lower sustainability. Still another effect of strength testing is through the role it has in optimisation and improvement. When testing variability is high it becomes more difficult to optimise the process, with the result that target values are frequently set at sub-optimal levels.

In Table 2 the total potential for improving value per price and value per harm was about 40%. Out of this up to half could be due to process and product variability with the rest being related to system limitations. Based on previous reasoning, ~50% of the total performance indicator variability could come from process variability affecting mainly emissions, ~25% from product variability and the remaining ~25% from testing variability. Based on this reasoning, about 10% of the total improvement potential could be due to testing variability.

5 Conclusions and discussion

Leading cement companies seem to be taking the issue of sustainability seriously and have embarked on a range of improvement activities and strategies for reducing the major environmental impact of CO_2-emissions. Stakeholder and customer focus are mentioned in these responses but there is no quantification of customer value, apart from the sales value. In this research work no mention has been found of the proposed indicators value/harm (MPa/ton CO_2) or value/price (MPa/US$*ton). Neither has any mention been found of the importance of variability reduction in the sustainability reports. This could be due to these indicators being omitted from the Global Reporting Initiative guidelines. It is therefore suggested that the proposed measures be assessed for incorporation in the Cement Sustainability Initiative, perhaps as a sector complement to the GRI guidelines.

The initial estimates formulated here indicate that there is a total potential of about 40% in improved value per price and value per harm to be realised on a global scale within the industry (Table 2). Up to one half of this potential could be due to excessive variability. While this obviously varies a lot between plants, the indications are that plants in Third World countries would have the most to gain from variability reduction. Here the chances for a win-win situation are better, as it could be assumed that more value for price would increase the sales, which would benefit the producers. The situation in most First World countries with mature markets is different. In this situation, it is important to find the key incentives needed to encourage plants to use their resources in the best way. It may be possible in the not-to-distant future to establish some kind of system with payment for performance.

Although minimizing variability will not solve more than a fraction of the cement industry sustainability problems, reducing it to the lowest practical levels is something which can be done at a relatively low cost. Understanding the impact of variability in all areas is important, including the area of measuring and testing. Investing in variability reduction programs could well be the investment with the shortest payback and one of the best returns for improving sustainability.

References

[1] WCED. Our Common Future: The Brundtland Report, Oxford University Press, Oxford, 1997
[2] R.E. Freeman, D.L. Reed. Stockholders and Stakeholders: A New Perspective on Corporate Governance. California Management Review. 25 (3), (1983,) 88-106
[3] L. Sörqvist. Poor Quality Costing. Doctoral Thesis No 23. Royal Institute of Technology, Stockholm, Sweden, 1988
[4] R. Isaksson. Economic Sustainability and the Cost of Poor Quality. Corporate Social Responsibility & Environmental Management, 12, (2005) 197-209
[5] WBCSD. Retrieved from www.wbcsd.org August 11, 2006
[6] EN 196-1:2005.