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Process based system models for detecting opportunities and threats – the case of World Cement Production

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Abstract

Background

Visualising change needs could be complex. One way of sense-making is to use process based system models. Global warming requires major changes in many fields and especially for cement manufacturing, which represents a growing portion of manmade carbon emissions. The industry has proposed measures for change, but it is difficult to assess how good these are and more sense-making is needed to clarify the situation.

Purpose

The purpose is to visualise opportunities and threats for global cement manufacturing in the context of global warming, using a process based system model.

Methodology

Available data for cement manufacturing and for carbon emissions are combined both historically and as predictions based on chosen Key Performance Indicators. These indicators are related to a chosen process based system model.

Findings

The results indicate that the global cement industry does not have a viable plan for how to reduce carbon emissions sufficiently to comply with the objectives of maintaining global warming below 2°C. The application of the process based system model indicates that it has the ability to visualise important opportunities and threats at the level of global processes.

Practical implications

The challenges of the world cement industry with reducing carbon emissions are highlighted. This information could be useful as a driver for change.

Originality/value

The paper provides insights into process based improvement work related to cement industry carbon emissions.

Keywords

Sustainability, Process Based Systems, Process, Cement Manufacturing, Carbon emissions. Global warming.

Article classification: Research

Background

Successful organisational change requires management commitment in the form of a sense of urgency and that most key players are aboard (Kotter, 1996). It could be that the process approach could be applied for its sense-making benefits as a prerequisite for organisational change. A process model combined with performance indicators could be used to try to make sense out of complex situations. The sense-making could then act as a driver for change at all levels of management.

Global warming attracts worldwide attention both in nations and organisations. The Business as Usual (BAU) approach is not viable and could according to IPCC (2013) lead to increases in the global temperature until 2100 of up to 6°C. There is common consensus that global temperature rise should be kept under 2°C or preferably under 1.5°C as agreed in the UN Conference on Climate Change COP21 in Paris November 2015. “Global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850 to 1900 for all Representative Concentration Pathways (RCP) except RCP 2.6” (IPCC, 2013). In order to achieve this reductions from the 2010 level of emissions in the order of 41-72% are needed until 2050 and reductions of 78-118% until 2100 based on the RCP 2.6 path. This indicates that all businesses with significant carbon emissions will face tough challenges in rethinking their production processes. One area with particular challenges is the global cement industry that reports its emissions as 5% of manmade carbon emissions (WBCSD, 2012), but with this percentage increasing due to the increase in global cement production. Scrivener (2014) reports the cement industry share of carbon emissions as 5-8%. This increase is predicted to grow further due to increasing production, which makes the global cement industry a suitable case for studying the sense-making abilities of a process based system model.

Isaksson (2006) proposes generic system based process models that can be used for describing the steady state and the change process. The process model in Isaksson (2006) and related measurements have been used and modified for different purposes such as analysing the measurement maturity (Isaksson and Hallencreutz, 2008), detecting supply chain innovation potential for sustainable development (Isaksson, et al. 2010) and using the model as a base for relative sustainability indicators (Isaksson et al. 2015). Isaksson (2015) proposes an Opportunity Study based on the generic process based system model (Isaksson, 2006). Opportunities are demonstrated at sub-process level, company level and for a region. This indicates that the model might work also at the level of global processes. An unattended improvement potential could also be seen as a threat when not acted upon. Opportunities and threats at the global level could be used as drivers for change – a way to create the sense of urgency. This model could possibly also be used for detecting opportunities and threats in processes on the global level.

The purpose is to visualise opportunities and threats for global cement manufacturing with carbon emissions using a process based system model.

Methodology

The approach proposed in Isaksson (2015) has been used. Data gathering and data analysis has been carried out with the purpose of demonstrating approximate figures to visualise the magnitude of challenges and opportunities. A target for reductions of carbon emissions based on the objective of maintaining global temperature increase below 2°C is defined with the starting point in IPCC (2014). The RCP 2.6 path is chosen and the reduction target is set at 70% by 2050 compared to 2006 levels. The year 2006 is chosen instead of 2006 due to the availability of some other data from this year. This corresponds approximately to a reduction of 65% from 2010 levels. This is in the upper part of the range proposed, but represents a

probable scenario that the industry might have to meet. Cement industry performance data are mainly collected from the Cement Technology Roadmap (WBCSD, 2009) and other documents from the Cement Sustainability Initiative (CSI) of the World Business Council of Sustainable Development (WBCSD).

Introduction to a process based system model

There are several definitions of processes. Isaksson (2006) proposes a synthesis that would not only include customers, but also stakeholders making it suitable for combined quality and sustainability improvement: “A process is a network of activities that, by the use of resources, repeatedly converts an input to an output for stakeholders”. This definition implies that resources should be something, which is part of the process notation. The process based system model for the steady state is presented in Figure 1.

Figure 1. A process based system model with proposed KPI used for describing the steady state (Isaksson 2015).

The model in Figure 1 follows the common process notation of separating management, main and support processes. Conforming to the chosen process definition, resources are also marked. The two proposed generic main processes are producing goods and services and marketing or communicating the value produced. Five types of measurements have been used (Isaksson and Garvare, 2003). These are Drivers, Input, Output, Outcome and Resources. Output is defined as the process result and Outcome as the stakeholder satisfaction of the Output. This has been described using the Triple Bottom Line using the Profit, People and Planet headlines. Dividing performance in output and outcome emulates the criteria in Excellence models such as the Swedish SIQ Model of Customer Oriented Business Development that differentiates between organisational results (criterion 6) and customer satisfaction (criterion 7) (SIQ, 2015). Drivers are external forces and could be described for example with the PESTEL-model (Political-Economic-Social-Technological-Environmental-Legal) (Burnes, 2009). These drivers could be coming from outside the system or as feedback from stakeholders. The stakeholder feedback passes a filter or amplifier of signals in the form of the external resources. Internal resources are described with a checklist based on a version

of the fishbone diagram with 7Ms that describe classes for common causes of problems such as Management, Method, Material, etc. (Bergman and Klefsjö, 2010). The list has been proposed as quick system check, increasing the number of M:s (Garvare and Isaksson, 2005), see Table I. The 10M:s are to be used for qualitative analyses of causes to a detected improvement potential. Process performance is described using six process dimensions, see Figure 1. Additional dimensions could be added if needed. Occupational safety and health is often in focus. This would in the example be found under the dimension Social. The indicator of Capacity could be seen to include time as indicator. The process dimension Value could be seen to include indicators such as profit and sales value but also customer utility.

Table I. 10M – check list for generic resources, based on Garvare and Isaksson (2005).

M – parameter	Criteria & comments
Mission	Purpose of the studied process - is it clear what it does and why and is this accepted and understood?
Management	Policies, goals and strategies for improving process performance in all relevant process dimensions? Maturity level of agreed principles. Organisational culture?
Method	Organisation of the process – is it managed as a process based on the principles of good process management – process maturity? Definition of competencies needed (Manpower specification). Organisational structure for carrying out strategies and achieving goals? Are there clear management systems and are they integrated?
Manpower	Competency for the required tasks. Competency could be seen as education, experience and attitude compared to specifications. Maturity of agreed principles.
Measurement	Maturity of measurement system and communication of performance results. Level of Measurement Information Systems (MIS).
Machine	Adequacy of equipment and premises for the intended use (specifications). Note that this also includes hardware and software for MIS and could also include service agreements.
Material	Methods for controlling incoming material and information. Level of specifications, deployment of these and results.
Milieu	Level of physical (effects both personnel and equipment) and social working environment.
Market	Customer base in the form of established relations, competition and general development level of the market. Includes also suppliers and relations to these.
Means	Availability of funds for operations, investments and improvements.

Performance could be seen in terms of relative indicators that compare value produced with harm done (Isaksson et al. 2015). Examples could be such as sales value/carbon emissions, customer utility/price and customer utility/environmental harm. The proposed generic indicators are used as a support in finding out which areas of performance that need attention. The question to be asked is how main elements of value and harm are measured? Essentially the issue is to find out how sustainable success can be measured in the studied system. This implies that an understanding of system limits is needed, which on the global level could be described as the planetary boundaries (Rockström et al., 2009). System limits are important to consider when indicators and targets for indicators are chosen.

In Figure 1, a change process is mentioned as one of the support processes. The logic is that in any organisation there is some type of improvement activity going on. It could be continuous improvement, which mainly takes place in the existing structure, or breakthrough improvement, which would be done in project form.

Change could be divided into creating the interest for change and changing (Isaksson, 2006). It could also be divided in the three steps of unfreezing, moving and freezing (Lewin, 1951). Unfreezing would already be seen as the first part of changing. Before unfreezing some type of change needs analysis should take place. Going from one steady state to another over a change process could be described as in Figure 2.

Figure 2. Change – breakthrough improvement - as going from one steady state over a change process to an improved steady state (Isaksson 2015). See also Figure 1 for details of the system change needs analysis.

Ideally any organisation or any process in it could be subjected to a change needs analysis. Isaksson (2015) proposes that one way of starting would be to carry out an Opportunity Study looking at the current state. An opportunity is defined as one where there is diagnosed improvement potential, where analysing of causes identifies reasons for the potential and where solutions are feasible. Additionally the opportunity should be something that the organisation is not currently working with. If an opportunity is detected and there is management commitment, then unfreezing could start (see Figure 2). Unfreezing would start with renewed diagnosing, analysing and solving (DAS) with the dual purpose of doing a more thorough assessment and with creating the commitment of those involved. The logic is that before deciding upon change an Opportunity Study is carried out using a quick DAS (Isaksson, 2015). The input to this could be based on important drivers for change as interpreted by management or by other stakeholders.

Below the logic for the Opportunity Study is tested by applying it on the global processes of producing cement with some discussing on how this would translate into concrete production. An opportunity could also be seen as a threat. This is when nothing is done to the improvement potential and where the non-realisation of this could be a problem for the organisation.

An Opportunity Study for the global process of cement manufacturing

Buildings, when seen as a process that goes from raw materials over concrete production, construction, use of buildings and to demolition consumes some 40% of the energy in the world (WBCSD, 2008). This corresponds roughly to 40% of the global carbon emissions (EPA, 2008). About 85% of the carbon emissions come from use of buildings. Out of the

remaining 15% a large part of the carbon emissions are attributed to cement manufacturing. Figures reported for global cement carbon emissions are 5-8 % of total global manmade carbon emissions (WBCSD, 2012), (Scrivener, 2014). Cement is the glue in concrete and often the most expensive component. Concrete is the most commonly used material in the world after water. There are other building materials, but in most cases concrete is the leading building material (Scrivener, 2014). Concrete based buildings play an important role for business and employment in practically all countries in the world – Profit. Providing shelter is on the base of Maslow's hierarchy of needs and therefore forms an important part of satisfying basic People needs. There are many environmental consequences from cement manufacturing and building, but by far the most important is the extremely high carbon footprint - Planet. Below, the results of an application of the Diagnosing-Analysing- Solving (DAS) logic (Isaksson, 2015).

Diagnosing

1. Choosing process scope

The process scope chosen is the global process of cement manufacturing. The raw material cement has a high carbon footprint and cement is often a cost driver. This means that cement plays an important role when studying sustainability in buildings. The global process of buildings is presented in Figure 3. The process of cement manufacturing is to be found in the sub-process of producing materials.

2. Preparing a process based system model for producing cement

In Figure 4 the process-based system model has been applied on the process of producing cement.

3. Choosing stakeholder focus

The stakeholder focus is visualised in Figure 4. Focus is on People and Planet needs in the form of building value, which for cement is described as strength*tons. This is a simplification, but based on the fact that the main purpose of cement is to glue together things. The more of this capacity, with everything else equal, the higher the value for the customer. The main problem with cement manufacturing is its high carbon footprint. This is therefore chosen as the main Planet harm indicator. The main People harm indicator chosen is the price. This applies specifically for the many poor countries of the world where building and cement price limits the availability of living space (Isaksson et al. 2010). Profit is only partly viewed using the indicators of sales value and carbon footprint.

4. Defining KPI that describe stakeholder satisfaction

From a People perspective the value required is adequate and affordable housing which could in its simplest way be measured as m² available per person compared to price in US\$. In poor countries cement is the driver of prices and cement performance per cement prices could therefore be used as an indicator that correlates with m²/price (Isaksson et al. 2010). The indicator for compressive strength is MegaPascal (MPa). This can be seen as the main building value for users. The higher the value and the more of material in tons the customer gets for the prices paid, the better the user value (MPa*tons), (Isaksson, 2015). The main planet harm is tons of CO₂-emissions with absolute limits related to global limits. Additionally relative indicators such as building value per carbon emissions and sales value per carbon emissions are of interest.

People

Building value of cement (MPa*tons)/ price (US\$/ton) (Isaksson, 2007), (Isaksson et al. 2015). The same indicator of MPa*tons could also be used for concrete.

Figure 3. The global building process with proposed important indicators.

Planet

Building value of cement (MPa*tons)/ ton CO₂

Profit

Sales value (US\$)/ton of cement

Sales value (US\$)/ton CO₂ (carbon productivity)

Cement prices vary and could in some cases be higher in developing countries, with quality being inferior (Isaksson, 2005). Cement price will therefore correspond to a larger part of the total cost of the accommodation in low-income countries. This could be seen as a social driver for companies to focus on making best use of cement strength in concrete applications.

5. Defining benchmarks based on system limits

Here, focus is on defining targets for carbon emissions where there are figures available. Cement compressive strength is also looked at, but not in any depth.

To calculate a current benchmark for the building value of cement in MPa*ton a strength of 60 MPa at 28 days is chosen (Isaksson, 2007). The strength classes in the European standard EN 197-1 have been the same since beginning of 2000. However, there exist methodologies such as clinker mineralisation, which could increase the 28 days strength of Portland Cement to some 75 MPa. The current average performance for concrete is assessed as 40 MPa for a concrete containing 15% by weight of cement in 2014 figures. This would translate to 267 MPa*tons (40/0.15). However, it is possible to produce high performance concrete of 200 MPa using chemical admixtures (Graybeal, 2006). Assuming 20% by weight of cement the

MPa*ton a future reference would be 1000 MPa*tons. These figure are used later to visualise possibilities with all options, see Table IV.

The price benchmark has been assessed as 60 US\$/ton. The current benchmark should be seen as an example.

Figure 4. The global process of cement manufacturing with proposed important indicators.

People benchmark

$60 \text{ MPa}/60 \text{ US\$} = 1 \text{ MPa}/\text{US\$}$, based on Isaksson (2007) and Alibaba (2015).

Planet benchmark

$60 \text{ MPa}/0.7 \text{ t CO}_2 = 86 \text{ MPa}/\text{ton CO}_2$, based on Isaksson (2007).

Profit benchmark

Carbon productivity for all value adding currently is about 2500 US\$/ton CO₂ where as it for cement is about 150 US\$/ton (Isaksson et al. 2015).

6. Comparing benchmark with current performance – the difference is the identified improvement potential

Improvement potential based on current performance is presented in Table II.

Table II shows that user value per price could be improved with a factor two and that user value per carbon emissions could be improved with about 50%. This indicates important opportunities for producing more value per harm in the current business. The big challenge is to cope with the requirements for future carbon reductions.

Table II. Assessing improvement potential based on current benchmark for People and Planet performance for cement.

Unit	Actual 2014	Benchmark 2014	Comments
MPa	50	60	Estimate for actual based on that most cements are class 32.5 and 42.5 or similar, which means that strength ranges are 32.5-52.5 and 42.5-62.5 MPa respectively at 28 days. The highest class in EN 197-1 is 52.5 indicating a minimum value for the compressive strength of 52.5 MPa.
Cement US\$/ton	100	60	Current average price is estimated based on US prices (Statista, 2015)
MPa/US\$	0.5	1	Benchmark quality could provide the same building needs for half the price
t CO ₂ /ton cement	0,87	0,7	Actual based on WBCSD (2009) and target at en estimated current best performance in 2014, see Table III
MPa/t CO ₂	57	86	

The calculations is based on 70% reduction from 2006 to 2050. In Table III some assessed comparative performance figures. The rate of reduction is based on WBCSD (2009) figures comparing 1990 and 2006. Extrapolation has been used for 2014.

Results in Table III indicate that cement industry carbon emissions in 2014 were almost 9% of global emissions compared to the figure of 5% reported by WBCSD (2012). Results indicate that the Cement Technology Roadmap measures are not going to lead to compliance with objectives set based on the RCP 2.6. The emissions, in spite of planned Carbon Capture and Storage (CCS), would indicate that the cement industry would be responsible for one quarter of manmade carbon emissions in 2050 (27%).

Other comments to Table III are that the earlier projections of world cement manufacturing have underestimated the growth. The figure in 2050 could therefore be on the low side. Provided the world manages to reduce carbon emissions in accordance with the targets required for limiting global warming to under 2°C, the cement industry performance will look very weak. Most of the planned improvement would be consumed by the increased production. The target in Table III based on the cement industry being responsible for 3.6% of global carbon emissions in 2050 indicates that the improvement has to be about 10 times more than indicated in the road map (WBCSD, 2009). The alternative is to limit cement production in 2050 to 10-15% of the predicted value in 2050 or to some 600-900 Mtons per year.

In Table IV a projection has been done using cement production target of about 750 Mt for 2050, which with the improvements complies with the reduction targets for CO₂. The cement quality benchmark of 75 MPa at 28 days has been used. The concrete has been calculated as high performance concrete of 200 MPa. The BAU 2050 represents the building value needed in MPa*tons. The table shows that complying with the CO₂-reduction objectives would only permit producing about 40% of the building value needed. This indicates that cement should only be used for applications where it is the most carbon effective solution and that other types of buildings not based on cement must be found.

Table III. Calculation of benchmark KPI for carbon emissions targets per ton of cement with a projection to 2050 with use of Carbon Capture and Storage.

	1990	2006	2014	2050	Comments
World Cement production (Mt)	1100	2700	4300	5600	2010 (Geopolymer, 2015), 2014 (Cembureau, 2014), 2050 based on projection (Geopolymer)
Clinker factor ton clinker/ton cement	0,83	0,78	0,76	0,71	Assessed based on roadmap CSI (2009)
Thermal efficiency (MJ/t clinker)	4,30	3,7	3,5	3,3	Assessed based on figures from CSI (2009) and extrapolated values for 2050
Kg CO ₂ /ton cement	759	680	660	420	Would be 620 kg 2050 if calculated based on Thermal efficiency improvement only (no effect from biofuels and no carbon capture and storage)
Carbon emissions kg per ton of clinker	916	872	868	592	Calculated from clinker percentage and ton CO ₂ /t cement (gross emissions for 2050 about 873 kg/ton of clinker)
Mt CO ₂	835	1836	2838	2352	Calculated from cement emissions and cement production (with 620 kg/ton cement the figure becomes 3472 Mt/year)
World CO ₂ -emissions (Mt)	23000	29000	33000	8700	2050 figure based on 70% reduction from 2006 values
Cement % of total emissions	3,6%	6,3%	8,6%	27%	The cement industry share in 2050, if CCS and other planned measures are not be taken would be about 40%
Target 2050 CO ₂ emissions	Mt/year			316	Based on 3.6% of total emissions
Target 2050	Reduction needed			87%	Compared to the Cement Technology Roadmap based prediction and 90% if CCS and extra measures are not deployed

Another challenge for the cement industry is the low carbon productivity. The benchmark in 2050 for world total GNP needs to be considerably higher than currently to allow for economic development of the poor world. This is while simultaneously reducing the carbon emissions. The value of World GNP/ton CO₂ could vary between 20 000 to 60 000 US\$ per ton CO₂ in 2050 depending on different assessments (Winston, 2014), (Isaksson et al. 2015). This means that the carbon productivity for cement should go from about 150 US\$/ton to 30 000 US\$/ton or an improvement of 200 times. This also indicates that cement and concrete solutions should be focused on the high value end.

Table IV. Current and benchmark performance for cement and concrete.

	1990	2014	BAU 2050	Objective 2050
World Cement production (Mt)	1100	4300	5600	752
Percentage clinker	0,9	0,82	0,71	0,71
Clinker used (Mt)	1000	3500	4000	500
Cement 28 days strength (MPa)		50	50	75
Concrete (15% cement by weight, 20% Objective 2050 - high performance concrete) (Mt)	7300	28700	37300	3800
MPa concrete – BAU 2050 value assessed as 50 MPa for 15% cement	30	40	50	200
MPa*ton concrete	200	267	333	1000
Million MPa*ton	220000	1150000	1870000	750000 (40% of BAU needs)

Analysing

1. Describe main y and x-es. The main cause for the high carbon footprint in cement is related to the raw material limestone that emits carbon as part of the production process. The reason for that the cement industry share of total carbon emissions is increasing is that the rate of improvement in the business is too slow compared to the global increase in cement use.

2. 10M analysis. The brief 10M-analysis indicates that Measurement is lagging. There seems to be little or no focus on improving the cement strength performance, which could be due to a logic reasoning that increasing cement strength would be detrimental to business in a mature market. Higher strength would lead to less cement being used in concrete. This could be seen as an issue of the Mission of cement business – maximising profits in the short term or being the company producing best value for resources and maintaining the license to operate in the long run. In developing countries needs for housing are enormous and the limiting factor is money. Improving m²/price by more MPa*tons should lead to increased sales and increased market shares. Value based performance figures are not generally used (Isaksson et al., 2015). Cement sustainability reports typically do not set any reduction targets related to global planetary limits. The Cement Sustainability Initiative (CSI) that could be seen as the process owner, has not set goals based on planetary limits and has not identified customer value. This could be partly due to the fact that the Global Reporting Initiative (GRI) guidelines, which are the dominating structure for sustainability reporting, have not identified customer value, but only refer to the sales value and its distribution (GRI, 2013).

Cement is manufactured in different cement classes. Taking the European EN 197-1 as an example there are three strength classes defined based on the minimum strength in MPa at 28 days as 32.5, 42,5 and 52.5. Cement performance could differ with up to a factor 2 depending on standard class. Sustainability performance is typically presented as carbon emissions per ton cement and not in relation to cement performance. Cement prices are rarely reported and it is practically impossible to compare user value to price.

3. Explaining main causes for identified improvement potential. The main cause seems to be lack of Management interest leading to a low relevance Measurement system. It could be a case of the old adage of: “what is not measured cannot be improved”. The current approach of Business As Usual (BAU) indicates that drivers for change are perceived as weak. One

explanation is that cement production is business to business, unlike e.g. flying that directly services customers. Here, criticism is common even if the world aviation industry is responsibly for only about 2% of world carbon emissions (ATAG, 2016). This indicates that Management does not have the sense of urgency (Kotter, 1996) to start major change. It could also be that Market drivers including legislation are weak. This in its turn would explain why relevant Measurement systems have not been developed.

4. Reviewing the on-going improvement in the studied process. The Cement Sustainability Initiative identifies four main levers for CO₂ reductions (CSI, 2015):

- Energy efficiency, via modern dry-process technology
- The use of alternative fuels (incl. biomass) to replace coal and petcoke in the cement kiln heating process
- The substitution of clinker with other mineral components in cement
- Carbon capture and storage (CCS)

The first lever of technology is widely considered of having come to its limits what comes to energy efficiency (Scrivener, 2014). There are still old kilns that could be replaced, but improved kiln energy efficiency will not solve the problem.

The second lever is focus on using alternative fuels, which means that cement kilns are used as incinerators. To the extent that biomaterials are used this could be deducted from the energy consumption. However, the proportion of biomaterials is still small and the main driver for using alternative fuels is economy. Companies are being paid to burn waste materials. This comes with a problem of increased complexity and variation of the fuel energy content. The result is often loss of capacity and increased specific energy consumption. The variation could also have an effect on the variability of clinker quality produced.

Third lever is reducing the clinker percentage by using substitutes such as fly ash, blast furnace and slag. However, amounts of the materials are globally limited (WBCSD, 2009), (Scrivener, 2014).

The fourth lever of CCS is assessed to make the main contribution. These proposed reductions for CCS might prove unrealistic because of high costs. It is estimated that applying CCS would increase the cement price 2-4 times (Scrivener, 2014), which could indicate that CCS would only be applied in the industrialised richer countries where as developing economies where cement prices already is a problem might not install CCS. Since the growing markets are in India and in Africa this indicates that the plans for CCS might not be realistic from a global perspective.

The conclusion is that current plans are not going to solve the problem. This means that there is an opportunity, which could be mainly a threat if there are no feasible solutions.

Solving

1) Describing a visionary new steady state. There seems to be no simple solutions. Results could indicate that the days of cheap cement should be over and that the use of cement should be restricted to more costly high performance applications only representing about 40% of the predicted cement use in 2050. For the remaining 60% of predicted needs other solutions need to be found. For low strength requirement one solution would be to use Supplementary Cementitious Materials such as geopolymers (Scrivener, 2014). Going back to old building techniques and natural building materials like rammed earth could also be a solution. Unfortunately steel and bricks are even more energy consuming materials than concrete. Wood could probable be used in some areas, but this would only be of marginal help. Increasing the price of cement would drive innovation for other materials and could promote

alternatives. Successively imposing a carbon tax could be one way to go. This would require major changes in finding cheaper alternative building materials in poor countries. Since employment in these countries is often a problem and labour is cheap the alternatives could be based on labour intensive building processes that could boost employment. Undeveloped markets might have opportunities in improving cement productivity. Isaksson (2015) describes the situation in Dar es Salaam, Tanzania, pointing out that the cement building strength potential is poorly used in the main cement application of solid sand and cement blocks. The MPa*tons produced are in the range of 50 MPa*tons corresponding to only about 20% of the current benchmark of 267 MPa defined in Table IV. Many of the applications are low strength ones where other materials, like stabilised earth, could be used. Higher cement prices could increase interest in other more sustainable materials. Based on the example of sand cement block making in Dar es Salaam it can be observed that technical solutions often are simple. However, the required knowledge and competence is missing both among customers and producers. The barriers for change could be more behavioural and cultural than technical. That is, substantial improvements could be carried out with better co-operation in regional supply networks where cement producers often are those with the best knowledge (Isaksson et al. 2010). Here, there are clear economic incentives and some change could be feasible provided there is interest and ownership for the opportunities.

2) Describing main steps in the change process. The first part of solving would be to establish better performance figures – strengthening the resource of Measurement - for the chosen relative indicators of: MPa*tons per carbon emissions and per price. The second step would be to agree upon targets that enable the cement industry to take its responsibility for not exceeding the +2°C limit. The issue needs a broader discussion by all interested parties including building companies and relevant authorities (Management).

3) Assessing if change is feasible. Change at the global level is not feasible unless strong management commitment, which currently is missing. It is logical that management of cement companies are not interested in reducing their production. It seems unfreezing is still not happening (see Figure 2).

Discussion

The target for carbon emission reduction could be discussed. We would need to get back to preindustrial levels of CO₂ in the atmosphere, which means going from the 2015 level of 400 ppm to 280 ppm. This would require negative emissions meaning that CO₂ sinks would need to be established. The reduction percentage chosen, 70% from 2006 levels could be even seen as low. Following the RCP2.6 scenario, emissions need to be zero by 2100. Another issue is what the world cement industry proportion of world carbon emissions should be? Here, the 1990 value of 3.6% has been chosen, since 1990 often has been a reference year in the Kyoto protocol. Lower reductions targets could have been chosen, but the main result would still be the same, which is that Cement Technology Roadmap (WBCSD, 2009) actions are insufficient. The purpose was to calculate the magnitude of change required and to set a reasonable target that can be used to demonstrate the effects on cement production and that currently proposed solutions are not viable.

Results indicate that major change is needed to the current plans. Since strength increase options in cement strength seem to be limited, focus could instead be on making better concrete with the help of additives. It might be better to produce less cement and save on CCS costs and instead invest this money into better additives for increased concrete strength.

The purpose of demonstrating an opportunity or in this case a threat is to use it as a driver for change. Whether this is the case has not been tested. One possibility of testing could be to send this paper to decision makers within the cement industry and record reactions.

The usability of the process models might need the familiarity, which comes after many years of use. Which, the right indicators are could be discussed from a sustainability perspective where main value per main harm indicators are constructed using a Pareto approach.

Conclusions

The share of the cement industry carbon emissions is growing and is per 2014 about 9% of manmade emissions (see Table III). When studying the Cement Technology Roadmap (WBCSD, 2009) for 2050 the results showed that the planned improvements are to a large part going to be consumed by the predicted increase in cement production. Even assuming that Carbon Capture and Storage (CCS) works, the cement industry percentage of global carbon emissions in 2050 would correspond to about 27% of global emissions, provided a global reduction of emissions with 70% based on 2006 values. The reduction projection is in accordance with the Representative Concentration Pathways RCP 2.6, which is the only ICCP scenario making it likely that global temperature increase will remain below 2°C compared to preindustrial levels and where there is a small chance to maintain temperature rise below 1.5°C (ICCP, 2014). Provided the cement industry would achieve the target of reducing emissions to the same percentage as it was 1990 – 3.6% - this would correspond to the production of some 750 Mt of cement per year in 2050, provided that the 420 kg of CO₂/ton of cement could be attained (see Table III). This corresponds to about 20% of current global production. Cement strengths have not been significantly improving during the last 15 years where as concrete strength has improved due to the use of additives. However some improvements could be envisaged. Assuming that cement compressive strength could improve from a current average of about 50 MPa to 75 MPa and that concrete could improve from an assumed current average of 40 MPa to high strength concrete of 200 MPa the MPa*tons generated would still correspond to only about 40% of the assessed building needs in a BAU scenario (see Table IV). This means that on top of all improvements for reducing carbon emissions and improving cement and concrete performance other building materials are needed for about 60% of the projected applications. The results indicate that cement should be reserved for the high performance concrete applications. Alternative solutions could be Supplementary Cementitious Materials and biomaterials such as rammed earth. The cement industry might have to rethink its entire business idea and go from a low cost commodity producer based on quantity to producing smaller amounts of customised high quality products.

The process based system model for describing a steady state (Figure 1) and the system change model (Figure 2) seem to support the assessment of opportunities and threats in a global level process. There is no clear owner of the global cement manufacturing process, but the WBCSD could via its Cement Sustainability Initiative (CSI) take the role. The first steps would be agreeing on relevant indicators and setting goals for the cement industry reduction of carbon emissions that enables the cement industry to take its responsibility for keeping to the RCP 2.6 scenario.

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