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Advancing environmental evaluation in cement industry in Iran

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ABSTRACT

Many developing countries strive to cover their need for cement by domestic productions. The rising number of cement factories in these countries gives evidence to this. However, the ambition comes along with considerable environmental impacts that can be attributed to this industry. Policy makers, manufacturers and the public are becoming more and more aware about the environmental issues attributed to cement production. Striving for an environmental friendly production of this good is an urgent need. This paper discusses how environmental evaluation of the cement industry in Iran can be facilitated. Up to now, there is no standard or coherent method available to proceed with the evaluation. To advance environmental evaluation, a set of appropriate indicators have been developed by cooperating with experts from university, industry and policy makers. Five representative cement factories in Iran were then surveyed to derive quantitative data for the indicators. This helped to picture the current performance of this industry sector. The importance of the indicators was determined with the help of the cooperating industrial partners. By using the TOPSIS method, indicators were prioritized and improvement strategies for this industrial sector were derived. 15 indicators are introduced; among them seven are for the intensity of consumptions during production of cement and emissions production, three for control of emissions to air, four for capacities of control of water pollution and one for the inefficiency level in the execution of ISO 14000. It shows that the last indicator has the highest priority followed by the intensity of CO_2 emission.

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1. Introduction

Since the United Nations Conference on Environment and Development in 1992, the concept of sustainable development (World Commission on Environment and Development (WCED), 1987) is more and more becoming a public concern. What started as a discourse among specialists has now become an important objective of policy makers (United Nations (U.N.), 1992), industries and media agendas. Efficiency in energy consumption or emission reduction in various products and processes are required from markets, and industries can no longer neglect this demand. Efficiency in resource consumption as well as including environmental aspects in industrial activities is regarded as a key strategic point for successful business. Considering environmental aspects have been given different names such as Ecodesign, Design for the Environment, Environmentally Conscious Design, Green Engineering, Sustainable Design, or Design for Sustainability amongst others (Waage, 2007; Howarth and Hadfield, 2006; Karlsson and Luttropp, 2006; McAloone, 2003; Coulter et al., 1995).

The increasing amount of published studies indicates the efforts to find appropriate ways of studying and communicating environmental performance of products and processes. Various methods and tools have been developed to assist in this endeavor. Life Cycle Assessment (LCA) as defined in ISO 14044 (ISO 14044, 2006) is one approach to analyze the environmental impacts occurring along the life cycle of a process or product (Valderrama et al., 2012). In literature, LCA is regarded as the most relevant tool to integrate environmental considerations into product development (Jeswiet and Hauschild, 2005; Germani et al., 2004; Nielsen and Wenzel, 2002; Erzner et al., 2001; Gertsakis et al., 1997). Many other tools are developed to be used in various industrial branches; many of them using simplified or abridged LCA (Erzner and Birkhofer, 2003; Ostad-Ahmad-Ghorabi, 2010; Goedkoop et al., 2004; Goedkoop and Spriensma, 2001).

Monitoring environmental performance by indicators – as defined by ISO 14031 (International Standard Organization: ISO 14031, 1999) – is another approach to determine environmental improvement strategies. Environmental performance is defined in ISO 14001 as "…measurable results of an organization's management of its environmental aspects…" (International Standard

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Organization: ISO 14001, 2004). ISO 14031 provides guidelines for the evaluation of environmental performance. Evaluation is facilitated by different indicators which are defined as "…specific expressions that provide information about an organization's environmental performance" (International Standard Organization: ISO 14031, 1999).

Environmental performance indicators are included in sets of sustainability indicators. They can be used for monitoring long-term effects of a policy in a region, country or in specific sectors of human activities. Various studies have been conducted regarding different types of environmental indicators and their role in environmental performance assessment (Azzone et al., 1996; Eagan and Joeres, 1997; Malkina-Pykh, 2000; Schultink, 2000; Olsthoorn et al., 2001; Niemeijer, 2002).

According to Jasch (2000), environmental performance indicators may have the following purposes (Jasch, 2000):

- Comparison of environmental performance over time
- Highlighting optimization potentials
- Derivation and pursuit of environmental targets
- Identification of market chances and cost reduction potentials
- Evaluation of environmental performance among companies (benchmarking)
- Communicational tool for environmental reports
- Feedback instrument for information and motivation of the workforce
- Technical support for Environmental Management Systems (EMS)

Schaltegger et al. (1996) recognizes four desired attributes of environmental performance indicators (Schaltegger et al., 1996):

- Comprehensible by non-scientists
- Suitable for an organization's environmental and social targets as well as to the information requirements of stakeholders
- Reliable
- Comparable across different organizations and relevant benchmarks

There is no standard set of indicators that is applicable for all industry branches or companies. Rather, the composition of indicators may vary from region to region, company to company and time to time. One reason here fore can be found in the basic differences between the quantity and quality of a company's processes and products. Another reason is the lack of standard methods for measuring parameters and identifying priorities for specific environmental issues in different regions of the world (Schultink, 2000; Olsthoorn et al., 2001).

In this paper, the environmental performance of the cement industry in Iran is investigated by setting up a model of suitable indicators. With the help of the indicators, priorities for further improvement strategies are set and recommendations for their implementation are derived.

2. Cement industry in Iran

Iran's cement industry is a subset of the non-metallic mineral industry. Cement production in Iran started formally with the opening of the first cement plant in 1934 which had a production capacity of 100 tons per day. The capacity of cement production in Iran was ever since rising and reached a production volume of 64 million tons in 2009. The big cities in Iran (such as Tehran, Mashad, Tabriz or Isfahan ….) have very polluted air. The old cement productions are situated near these cities and had enormous contribution on pollution over the years. The newer factories are situated near mountains where smaller cities and villages are located. Around 1995, the parliament has declared cleaner production in this industry branch as an important strategic goal. Installing modern filters and using new production methods to reduce the emissions were one way to meet this goal. The financial investments were reflected in the final cement price: cement price has risen more than two hundred percent in Iran since then (Bahadori, 2011; Khademi and Maghulparast, 2012).

The production volume of cement in Iran has positioned Iran in the world's top fifteen countries for cement production (Portal of Iran's Cement I, May 2010). As a matter of fact, increasing production volume has been the main priority in Iran's cement industry in the last decades. Considering the emissions and pollutions emerging from this industry branch, it becomes essential to take steps towards further reducing environmental impacts. This has been neglected over the years. In the stream of sustainable development, recognizing potential environmental improvement strategies and setting policy priorities for the cement industry in Iran is a major concern.

The cement manufacturing process follows three major steps (Navia et al., 2006):

1. Preparing raw materials (mixing/homogenizing, grinding and preheating),
2. Burning of raw meal to form cement clinker in the kiln,
3. Grinding of clinker and mixing with additives.

Limestone rock (75–80%) and clays (20–25%) are the main raw materials in the clinker production. Limestone rock supplies calcium carbonate ($CaCO_3$) which is necessary for cement production. Calcium carbonate is present in limestone rock (up to 95%). The main clay components are: around 65% calcium oxide or lime (CaO), 22% silica (SiO_2), 6% alumina (Al_2O_3) and 6% iron oxide (Fe_2O_3).

The mixture of raw materials is milled to a final particle size of less than 300 μm, obtaining a fine powder called raw meal, which goes through the clinkerization process. In this process, the raw meal is treated thermally in the kiln at temperatures up to 1450 °C corresponding to a gas temperature of about 2000 °C. This process delivers a transformed vitreous material. In this stage, the $CaCO_3$ is thermally decomposed into CaO and CO_2.

A cooling process of the clinker (from 1450 °C to 200 °C) is required to stop the reactions and facilitate the calcium compounds' final crystallization. The clinker (80%) is then mixed with gypsum and other additive materials (20%) and milled to produce the final cement. Different additive materials (e.g. high-purity limestone, puzzolane, fly ashes or glass slag) are responsible for the characteristics of the final cement and its mechanical properties (Navia et al., 2006; Kaantee et al., 2004).

Although new processes are proposed to reduce pollutions (Benhelal et al., 2012), cement production remains a highly polluting process. Main pollutions of cement industry are: physical pollutions (e.g. dust and Suspended Particle Matter (SPM)); chemical pollutions (e.g. Sulfur dioxide (SO_2) and Nitrogen oxides (NO_x)); Greenhouse gases, namely Carbon dioxide (CO_2) and other pollutions (e.g. different wastes, noise, wastewater, land pollution and oil leakage) (Morlowe and Mansfield, 2002; Monavari, 2005).

3. Methodology

In this paper a model is developed that enables to study the environmental performance of cement industry in Iran. Four steps are followed to set up the model:

1. Determination of environmental indicators,
2. Determining relative importance of the indicators,

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3. Data collection and
4. Prioritization.

Each of the steps is explained in detail in the following.

3.1. Determination of environmental indicators

Available indicators for the evaluation of the environmental performance of industries link causes and effects of industrial activities to the state of the four resource groups, i.e. air resources, water resources, land resources, mineral and energy resources (Olsthoorn et al., 2001; Azapagic and Perdan, 2000). There is no consensus on a consistent methodology to measure these causes or effects. However, many quantitative and qualitative methodologies have been proposed (Olsthoorn et al., 2001; Azapagic and Perdan, 2000). Nonetheless, indicators developed through this paper should be able to reflect relevant impact categories of the cement industry. At the same time, these indicators should allow the proposal of appropriate strategies and guidelines to improve the environmental performance.

Some environmental impacts of industries according to Wenzel et al. (1997) are (Wenzel et al., 1997):

- Global warming (in trace of gases as carbon dioxide and methane)
- Depletion of stratospheric ozone
- Acidification (in trace of gases such as sulfur dioxide or nitrogen oxides)
- Increase of nitrogen and phosphor in lakes
- Increase of troposphere ozone formation potential
- Decrease of non-renewable resource

To address these impact categories, some key indicators for environmental performance are defined in the Global Reporting Initiative (GRI) guidelines (Global Reporting Initiative (GRI), 2000) such as: energy use, use of materials and resources, use of water, emissions/effluents/waste, suppliers, impacts of products, services and transport, land use/biodiversity and compliance.

Some operational environmental performance indicators defined in ISO 14031 (manufacturing sector) (International Standard Organization: ISO 14031, 1999) are: materials use, energy use, wastes, emissions to air, effluents to water and land, other emissions (noise, vibrations, etc…).

To achieve improvements in the aforementioned impact categories through indicators, some recommendations for general cleaner production management strategies can be taken (Glavi and Lukman, 2007):

- Increase the productivity of materials
- Improve energy efficiency
- Improve material flow management
- Apply preventive environmental protection approaches
- Strive for sustainable use of natural capital
- Achieve accordance with legal compliance

To be able to address the aforementioned impact categories and evaluate the environmental performance by appropriate indicators, some additional issues need to be considered:

- Specific conditions in Iran and the cement industry in Iran; in particular, it was aimed to balance the scientific description of the indicators and their applicability and acceptance in industry.
- Indicators were stated as intensities (indicators' amount to production amount) to facilitate a comparison between different factories and different production volumes.
- In case of NO_x, SO_2 and Suspended Particular Matter (SPM), indicators were categorized in those applicable for prevention (before pollutions occur) and those applicable for controlling purposes (after pollutions occur). For all other cases, this distinction was not applied.
- Indicators for heat and electrical energy consumption are considered separately. CO_2, NO_x or SO_2 emissions can be assigned to both, heat and electrical energy consumption. However, according the Kyoto protocol, emissions of electrical energy have to be assigned to the producer of electrical energy. Since cement industries in Iran have no electricity production on site (Portal of Iran's Cement I, May 2010), no emissions from electricity energy production can be assigned to them. Should electricity production on site become an issue in future, the separated indicators can be considered.
- The set of indicators should be able to cover all input and output flows of the cement production process. The flow process is shown in Fig. 1.
- In addition to the input/output indicated in the flow process, the use of water within the process must be considered too.

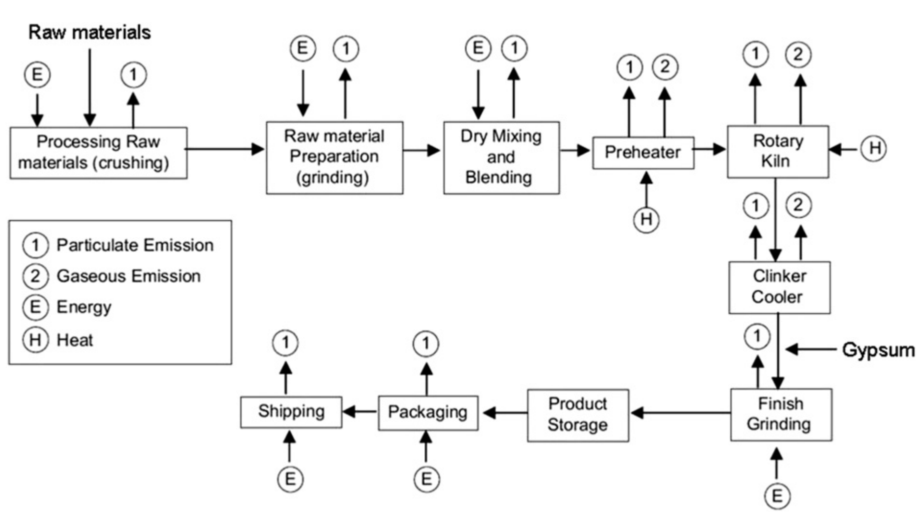

Fig. 1. Process flow diagram for the cement manufacturing process with inputs and outputs (Huntzinger and Eatmon, 2009).

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Water is needed for producing grout from raw materials, for cooling machineries and for washing cement and material mills. These processes contribute to considerable water pollution and specific indicators will be dedicated to this issue.

In a first attempt, a number of indicators were postulated by going through a brainstorming session with four university professors familiar with the concepts of environmental performance evaluation and the cement industry. After a short briefing on the goal of the brainstorm, they were asked to set up indicators which were able to address relevant impact categories by considering ISO 14031 and the GRI guidelines as well as specific aspects of the region/country and the cement industry in Iran. The proposed indicators were then categorized in those describing raw materials, energy consumption (electrical and heat) and emissions. Emission indicators were further distinguished between intensity and controlling indicators. Water pollution was given a separate indicator. The set of preliminary indicators was compared to some similar studies conducted in the field of cement industry (Von Bahr et al., 2003). It showed that the proposed indicators were similar in content. This was seen as good enough evidence for the appropriateness of the proposed indicators at this stage in order to proceed with the next step.

With this preliminary set of indicators at hand, in the next step, a group of twenty experts were interviewed to determine whether any important indicator is missing or not. The group of experts comprised of four directors from the Department of Environment in Iran, four environmental experts from Industries and Mines Organization of Iran, two professors in the field of environmental management of Islamic Azad University in Iran and ten experts from cement industry working in the department of environmental management. The interview protocols were analyzed in order to find possible new indicators.

The final set of indicators was then evaluated as to their internal consistency using Cronbach's alpha. The set of indicators was then again handed to the group of experts to determine the weighting factors.

The preliminary list of indicators gained through the brainstorm session resulted in a list of 14 indicators, which were:

- I_1: Intensity of raw materials consumption in production
- I_2: Intensity of electrical energy consumption in production
- I_3: Intensity of heat energy consumption in production
- I_4: Intensity of emissions to air, contain CO_2
- I_5: Intensity of emissions to air, contain NO_x
- I_6: Intensity of emissions to air, contain SO_2
- I_7: Intensity of emissions to air, contain SPM
- I_8: Control factor of emissions to air, contain NO_x
- I_9: Control factor of emissions to air, contain SO_x,
- I_{10}: Control factor of emissions to air, contain SPM
- I_{11}: Capacity of control of water pollution, contain Chemical Oxygen Demand (COD)
- I_{12}: Capacity of control of water pollution, contain Biochemical Oxygen Demand (BOD)
- I_{13}: Capacity of control of water pollution, contain Total Suspended Solids (TSS)
- I_{14}: Capacity of control of water pollution, contain pH

The intensity indicators provide the ability to compare the emission production between different companies. The control factor indicators link to the controlling methods after emission production and also to their prevention.

To determine whether this set of indicators is enough or not, twenty experts were interviewed individually with a questionnaire. They were asked to weight every indicator in percent. Some argued that there are other indicators to be included. However, they all agreed that their relative importance is not significant. Nevertheless, to include all indicators that might not be reflected in the preliminary set of indicators, an additional indicator was introduced. This indicator shall cover the effects of all those indicators not present in the aforementioned list of 14 indicators. It describes the inefficiency level in the execution of ISO 14000. Hence, this indicator is named:

- I_{15}: Inefficiency level in the execution of ISO 14000.

This approach is seen as an applicable compromise, since all selected factories are ISO 14000 certified. This last indicator is, unlike I_1–I_{14}, qualitative rather than quantitative. A bipolar scale (Hwang and Yoon, 1981; Hwang and Lin, 1987) is chosen to qualify this parameter: $9 =$ very high inefficiency, $7 =$ high, $5 =$ average, $3 =$ little and $1 =$ very little inefficiency.

Cronbach's alpha was calculated to check internal consistency of the indicators using the evaluation of the experts. With $\alpha = 0.758 > 0.7$ the scale is considered to be of good quality and the indicators consistent.

3.2. Relative importance of indicators and data collection

Since there was no official statistical data about the emissions and impacts of the cement industry in Iran available, it was necessary to gather this information by observing some factories. Companies certified by ISO 14000 and those having some sort of documentation on their environmental impacts were considered to be suitable for this survey. With the help of the expert group, a questionnaire was designed to find out the relative importance of each indicator. Five different cement factories were surveyed and were asked to quantify the indicators based on their processes and assign a relative importance factor them, expressed as percentage (weighting factor). The answers were averaged and normalized.

3.3. Prioritization of environmental indicators

To prioritize the indicators based on the quantities and relative importances achieved in the previous step, a Multi-Criteria Decision Making (MCDM) model has been selected for this purpose (Hwang and Yoon, 1981; Hwang and Lin, 1987). One of the methods that is used in the MCDCM model is the Technique for Order-Preference by Similarity to Ideal Solution (TOPSIS) (Hwang and Yoon, 1981) which is used in this paper.

The purpose in MCDM models is to facilitate the selection of one option among the others. Generally, these models are formularized by a decision matrix (D). Columns constitute criteria and rows the options (here, indicators).

$$D = \begin{bmatrix} r_{11} & r_{12} & r_{13} & \cdots & r_{1n} \\ r_{21} & r_{22} & r_{23} & \cdots & r_{2n} \\ r_{31} & r_{32} & r_{33} & \cdots & r_{3n} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ r_{m1} & r_{m2} & r_{m3} & \cdots & r_{mn} \end{bmatrix} \quad (1)$$

Each element of the decision matrix r_{ij}, with $i = 1 \ldots m$ and $j = 1 \ldots n$ (in our case $m = 15$, $n = 15$) is the relative distance of the indicator value from the standard value and can be calculated by:

$$r_{ij} = i_i \times \frac{s_j - k_j}{s_j} \quad (2)$$

Where i_i is the relative importance of the indicator, s the standard value and k the indicator value.

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To establish the decision matrix, indicator values must be specified for the selected companies in Iran relative to a reference level. This reference level was chosen to be the indicators' universal standard value in the cement industry based on data from the World Bank Group (World Bank Group, May August 2010). For most indicators, standard values can be found. For those indicators without a standard reference, an average value is taken. The average value is derived by considering the indicator values of three industrialized countries, namely United Kingdom, Germany and Canada. According to Yale Center for Environmental Law & Policy (Yale Center for Environmental Law and Policy, 2008), these countries were considered to be well performing on environmental indicators in the sector of cement industry.

With the decision matrix at hand, indicators can be prioritized using the TOPSIS algorithm (Hwang and Yoon, 1981; Hwang and Lin, 1987). According to this algorithm, the problem is solved using the following steps:

Step 1. The decision matrix is normalized to derive unit-free elements. A linear scale transformation is used as follows:

$$n_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} r_{ij}^2}} \tag{3}$$

where n_{ij} is the normalized value of r_{ij}.

Step2. Obtain the weighted normalized decision matrix (V), as follows:

$$V = N_D \cdot W_{n\times n} = \begin{bmatrix} V_{11} & \dots & V_{1j} & \cdots & V_{1n} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ V_{m1} & \cdots & V_{mj} & \cdots & V_{mn} \end{bmatrix} \tag{4}$$

where N_D is the normalized decision matrix and $W_{n\times n}$ is the weight matrix, which here is equivalent for all companies ($V = N_D$).

Step3. Obtain the positive ideal solution (A^+) and the negative ideal solution (A^-), as follows:

$$A^+ = \left\{ (\max_i V_{ij} | j \in J), (\min_i V_{ij} | j \in J') | i = 1,2,\dots,m \right\} = \left\{ V_1^+, V_2^+, \dots, V_j^+, \dots, V_n^+ \right\} \tag{5}$$

$$A^- = \left\{ (\min_i V_{ij} | j \in J), (\max_i V_{ij} | j \in J') | i = 1,2,\dots,m \right\} = \left\{ V_1^-, V_2^-, \dots, V_j^-, \dots, V_n^- \right\} \tag{6}$$

As, $J = \{j = 1,2,\dots,n\}$ is an attribute benefit and $J' = \{j = 1,2,\dots,n\}$ is an attribute cost (here, all of indicators are costs).

Step4. Obtain the separation measures d_{i+} andd_{i-}. Separation measures are defined as:

$$d_{i+} = \left\{ \sum_{j=1}^{n} \left(V_{ij} - V_j^+ \right)^2 \right\}^{0.5} ; \quad i = 1,2,\dots,m \tag{7}$$

$$d_{i-} = \left\{ \sum_{j=1}^{n} \left(V_{ij} - V_j^- \right)^2 \right\}^{0.5} ; \quad i = 1,2,\dots,m \tag{8}$$

Step5. Compute the relative closeness to ideals (c_{i+}), as follows:

$$c_{i+} = \frac{d_{i-}}{(d_{i+} + d_{i-})}; \quad 0 \le c_{i+} \le 1; \quad i = 1,2,\dots,m \tag{9}$$

Step6. Prioritize options (here indicators) based on descending rankc_{i+}.

4. Results and discussion

Cronbach's alpha, see Equation (10), is used to evaluate the internal consistency of the final set of indicators obtained from measuring tools, e.g. questionnaire:

$$\alpha = \left(\frac{J}{J-1} \right) \left(1 - \frac{\sum S_J^2}{S^2} \right) \tag{10}$$

Where J is the number of test questions (items), S_J^2 variance of $J'th$ under set, and S^2 is the variance of the whole test. $\alpha = 1$ means full credibility and $\alpha = 0$ no credibility.

The reliability of a spectrum can never be less than Cronbach's alpha even if the items are not measure in parallel. In other words, in most cases alpha is a conservative evaluation of reliability (Carmines and Zeller, 2007). With the list of indicators at hand, five

Table 1
Quantity and relative importance of environmental indicators for several cement companies in Iran.

Indicator		Company (1)	Company (2)	Company (3)	Company (4)	Company (5)	Unit	Relative importance		Indicator number
Intensity of raw materials consumption		1.64	1.60	1.58	1.7	1.7	t/t Product	10		1
Intensity of electrical energy consumption		101.35	103	95.37	100.80	98.45	kWh/t Product	10		2
Intensity of heat energy consumption		828	814	801.45	842.50	850	kcal/kg Product	15		3
Intensity of emissions production to air	CO_2	906	900	923	1000	940	kg/t Product	35	25	4
	NO_x	2.22	2.37	2.25	3	2.50	kg/t Product		2.5	5
	SO_2	1.14	1.36	1.28	1.45	1.24	kg/t Product		2.5	6
	SPM	0.42	0.58	0.63	0.71	0.64	kg/t Product		5	7
Control factor of emissions to air	NO_x	351	378	422	470	435	ppm	10	2.5	8
	SO_2	433	486	514	605	574	ppm		2.5	9
	SPM	30	151	105	114	98	ppm		5	10
Capacity of control of water pollution	COD	54	62	65	109	60	mgr/l	5	1.25	11
	BOD	17	41	38	52	45	mgr/l		1.25	12
	TSS	52	58	64	75	7.8	mgr/l		1.25	13
	pH	5.60	6.80	7.50	10	7.80	mgr/l		1.25	14
Inefficiency level of execution of ISO 14000		5	5	5	5	5	–	15		15
							Total	100		

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different cement factories were asked to assign quantity and relative importance to each of the indicators. The results of the survey are listed in Table 1.

Table 2, provides the considered standard values for indicators plus their average value in three industrialized countries.

For example, to calculate the element r_{41} of the decision matrix, we read on the 4th row of two tables, $i_i = 25$ from the 8th column in Table 1, $s = 731$ from 7th column in Table 2, $k = 906$ in second column in Table 1. Equation (2) results with the value $r_{41} = -5.985$. The decision matrix is then

$$D = \begin{bmatrix} -1.233 & -0.959 & -0.822 & -1.644 & -1.644 \\ -1.924 & -2.118 & -1.220 & -1.859 & -1.582 \\ -1.560 & -1.280 & -1.029 & -1.850 & -2.000 \\ -5.985 & -5.780 & -6.566 & -9.200 & -7.148 \\ -0.583 & -0.792 & -0.625 & -1.667 & -0.972 \\ -0.667 & -1.278 & -1.056 & -1.528 & -0.944 \\ -0.250 & -2.250 & -2.875 & -3.875 & -3.000 \\ -0.425 & -0.650 & -1.017 & -1.417 & -1.125 \\ -0.206 & -0.538 & -0.713 & -1.281 & -1.088 \\ 3.000 & -5.067 & -2.000 & -2.600 & -1.533 \\ 0.575 & 0.475 & 0.438 & -0.113 & 0.500 \\ 0.825 & 0.225 & 0.300 & -0.050 & 0.125 \\ 0.167 & 0.042 & -0.083 & -0.313 & -0.375 \\ 0.173 & -0.058 & -0.192 & -0.673 & -0.250 \\ -60.000 & -60.000 & -60.000 & -60.000 & -60.000 \end{bmatrix}$$

Equation (4) delivers the normalized matrix as:

$$N = \begin{bmatrix} -0.020 & -0.016 & -0.014 & -0.027 & -0.027 \\ -0.032 & -0.035 & -0.020 & -0.030 & -0.026 \\ -0.026 & -0.021 & -0.017 & -0.030 & -0.033 \\ -0.099 & -0.095 & -0.109 & -0.151 & -0.118 \\ -0.010 & -0.013 & -0.010 & -0.027 & -0.016 \\ -0.011 & -0.021 & -0.017 & -0.025 & -0.016 \\ -0.004 & -.0037 & -0.048 & -0.063 & -0.049 \\ -0.007 & -0.011 & -0.017 & -0.023 & -0.019 \\ -0.003 & -0.009 & -0.012 & -0.021 & -0.018 \\ 0.050 & -0.084 & -0.033 & -0.043 & -0.025 \\ 0.010 & 0.008 & 0.007 & -0.002 & 0.008 \\ 0.014 & 0.004 & 0.005 & -0.001 & 0.002 \\ 0.003 & 0.001 & -0.001 & -0.005 & -0.006 \\ 0.003 & -0.001 & -0.003 & -0.011 & -0.004 \\ -0.993 & -0.990 & -0.992 & -0.983 & -0.990 \end{bmatrix}$$

As suggested before, $V = N_D$. The Equations (6) and (7) deliver the positive and negative solutions:

$$A^{+} = [-0.993 \quad -0.990 \quad -0.992 \quad -0.983 \quad -0.990]$$

$$A^{-} = [0.050 \quad 0.008 \quad 0.007 \quad -0.001 \quad 0.008]$$

The separations measures d_{i+} and d_{i-} from Equations (8) and (9) and then the relative closeness to ideals c_{i+} from Equation (10) are calculated as follow:

$$(d_i^{+}) = \begin{bmatrix} 2.166 \\ 2.148 \\ 2.155 \\ 2.957 \\ 2.178 \\ 2.172 \\ 2.122 \\ 2.178 \\ 2.184 \\ 2.154 \\ 2.226 \\ 2.223 \\ 2.208 \\ 2.205 \\ 0.000 \end{bmatrix} \quad (d_i^{-}) = \begin{bmatrix} 0.088 \\ 0.106 \\ 0.098 \\ 0.291 \\ 0.074 \\ 0.079 \\ 0.123 \\ 0.073 \\ 0.067 \\ 0.113 \\ 0.040 \\ 0.037 \\ 0.050 \\ 0.051 \\ 2.245 \end{bmatrix} \quad \Rightarrow (c_i^{+}) = \begin{bmatrix} 0.039 \\ 0.047 \\ 0.044 \\ 0.129 \\ 0.033 \\ 0.035 \\ 0.055 \\ 0.032 \\ 0.030 \\ 0.050 \\ 0.018 \\ 0.016 \\ 0.022 \\ 0.023 \\ 1.000 \end{bmatrix}$$

c_{i+} gives the priority rank of the indicators as follows:

$$I_{15} > I_4 > I_7 > I_{10} > I_2 > I_3 > I_1 > I_6 > I_5 > I_8 > I_9 > I_{14} > I_{13} > I_{11} > I_{12} \quad (11)$$

As seen from the indicator priority ranking, indicator I_{15} has the highest priority. This indicator is a qualitative indicator and relates to promotion of environmental management in a company. The next important indicator is I_4 which is the intensity of CO_2 emissions to air. In fact, I_4 constitutes the most representative indicator for sustainability in the cement industry with high potential for improvement. However, comparing the indicator value of I_4 in Iran with other industrialized countries such as UK, Germany and Canada, it shows that I_4 is not performing outraging worse (compared to Germany around 50%, to Canada around 22% and UK around 13% worse). The general need for CO_2 emissions reduction in the cement industry has to be emphasized here.

Table 2
Quantity of environmental indicators for cement industry in developed countries and their standard values (BCA, 2010; Z (Verein Deutsche Zeme, June 2010; CAC, 2010; World Bank Group:ui, June 2010).

Indicator		British cement (BCA) 2008	Germany cement (VDZ) 2007	Canada cement (CAC) 2006	Average	HSE guidelines for cement 2007	Standard	Unit	Indicator number
Intensity of raw materials consumption		1.43	1.50	1.44	1.46	–	1.46	t/t Product	1
Intensity of electrical energy consumption		82	79	86	–	85	85	kWh/t Product	2
Intensity of heat energy consumption		665.40	660	670	–	750	750	kcal/kg Product	3
Intensity of emissions production to air	CO_2	819	614	760	731	–	731	kg/t Product	4
	NO_x	1.85	1.75	1.8	1.8	–	1.8	kg/t Product	5
	SO_2	0.91	0.88	0.92	0.90	–	0.90	kg/t Product	6
	SPM	0.11	0.12	0.27	–	0.4	0.4	kg/t Product	7
Control factor of emissions to air	NO_x	268	200	273.50	–	300	300	ppm	8
	SO_2	314	250	307.80	–	400	400	ppm	9
	SPM	25	15	20	–	75	75	ppm	10
Capacity of control of water pollution	COD	51.60	43	55	–	100	100	mgr/l	11
	BOD	15.90	12	18	–	50	50	mgr/l	12
	TSS	44	40	51	–	60	60	mgr/l	13
	pH	6.50	6	6.8	–	6.5	6.5	mgr/l	14
Inefficiency level of execution of ISO 14000		1	1	1	1	–	1	–	15

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Fig. 2 shows the comparison of the different indicator values in Iran and the three developed countries UK, Germany and Canada. To fit all indicators into one chart, the units of the indicators have been adapted, as noted below the chart. I_{15} is excluded from the graph as it is a qualitative and not a quantitative one.

Based on the priorities and quantities derived for the indicators, improvement strategies can be obtained. The highest priority is given to CO_2 emission reduction, in general reduction of emissions to air. This is shown by the indicators I_4, I_7 I_{10} or I_3 which are among the higher prioritized indicators.

5. Conclusion and outlook

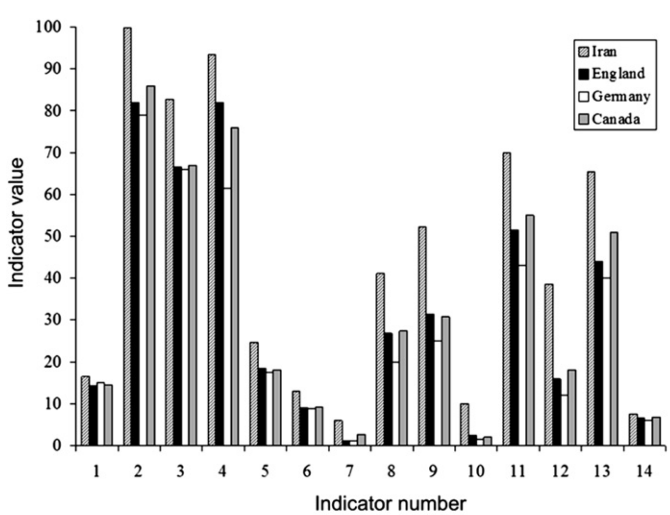
Strategies suggested in literature that can be taken as basis for further improvement of emissions to air are (Hendriks et al., 2004; Gartner, 2004; Damtoft et al., 2008):

1. Alternative fuels, replacing high-carbon fuels by low-carbon fuels
2. Alternative raw materials
- Alternative raw materials for the replacement of limestone in kiln feed
- Alternative raw materials, contain non-carbonate calcium
3. Reduce clinker contents in cement, e.g.
- Granulated Blast Furnace Slag (GBFS) and fly ash
- Puzzolans
- Silica fume
- Other Supplementary Cementitious Materials (SCMs)

I_2 and I_3, both indicators for energy consumption, can also be found in the first third of prioritized indicators, showing the relevance of introducing energy efficient processes for the cement production sector. Hence, the strategy proposed for this case is (Worrell and Galitsky, 2008; Khademi and Maghulparast, 2012):

6. Energy efficiency improvement and shifting to more energy efficient processes

The question that arises at this point is how these strategies can be successfully implemented? Iranian government has started a campaign called subsidy reform plan, in which subsidies for energy are being removed stepwise. The consequence of this campaign is increased prices for natural gas, electricity and fuel. All industry branches, and among them the cement industry, will need to think of energy efficient processes seriously. Up to now, no standardized approach or guidelines are available for the Iranian cement industry to succeed in this endeavor.



(Indicator, Unit): (1, t/10t product); (2, kWh/t product); (3, 10kcal/kg product); (4, 10kg/t product); (5, kg/10t product); (6, kg/10t product); (7, kg/10t product); (8, 10ppm); (9, 10ppm); (10, 10ppm); (11, mgr/l); (12, mgr/l); (13, mgr/l); (14, mgr/l)

Fig. 2. Comparison of the indicators in Iran and three developed countries.

A consequent next step in this project is to set up an alliance of cement producing factories to work out guidelines and recommendations for the implementation of the improvement strategy. This requires a detail audit and analysis of current processes and the development of new, improved and more efficient ones. This will need a close cooperation between manufacturers and policy makers. To motivate cement industries to implement sustainable thinking, some suggestions are mentioned here:

- Obligation for the use of sustainable thinking for tax exemption and seizure of credits,
- Obligation for the establishment of environmental management systems
- Introduction of subjects considering sustainable thinking and ecodesign in engineering studies in universities,
- Implementation of incentives for companies using environmental friendly and sustainable production technologies,
- Recording exact environmental statistics of activities in the cement industry.

Trading CO_2 certificates or providing tax incentives can help to implement strategies for the reduction of air emissions. Both approaches have already been discussed with policy makers and experts; due to their positive feedback, this option will be further followed in future research activities.

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