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Prioritizing Energy Efficiency Measures in the Cement Industry using decision making techniques

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Abstract

Cement industry is an energy intensive sub-sector consuming almost 15% of total energy used in the entire industry. Hence, numerous energy efficiency measures have been introduced and applied within recent decades. To evaluate and select the most appropriate measures for a certain cement plant, both technological constraints and managerial criteria should be taken into account. To date, decision makers have often focused on particular characteristics of measures solely, such as amount of energy savings, costs of investment and emission reduction. In the conventional approaches, some qualitative criteria are missing, the current condition of the factory is mostly overlooked and the possible conflictions throughout decision making process are not managed. In this study, we develop an integrated and comprehensive model to assist decision makers to overcome these shortcomings. The model includes three phases. In the first phase, factors influencing energy use are investigated. In the second phase, budgetary, economic and time constraints, as well as managerial goals and decision making criteria and their preference are dealt with. Then, energy efficiency measures are prioritized using a combined decision making techniques. In the last phase, a brief economic evaluation will be carried out for selected measures to ensure that the outputs are applicable and cost effective.

Keywords*:* Cement Industry, Decision Making, Energy Efficiency

1. Introduction

Cement plays an essential role in economic growth especially for developing countries. However, its production associates with highly energetic and CO2 emitting processes. Cement industry consumes almost 15% of total energy used in the entire industry [1]. In average, to produce one ton of cement, 3.4 GJ/t (in dry process) and 110 Kwh of thermal and electrical energy are required, respectively [2, 3]. This amount of energy is nearly equal to 0.1 tons of oil equivalent [4]. In the other hand, depending on the employed technologies, producing one ton of cement releases up to 990 kg CO_2 to the atmosphere. This implies a notable impact on the environment [5]. Within the last decade, annual cement production has increased rapidly and has risen up to 3.4 billion tones in 2012[6].

Recent technologies in this industry have focused on improving energy efficiency while trying to maintain the quality and capacity of production. There are a wide variety of introduced and commercialized measures to reduce the energy consumption and CO_2 emission. These achievements could be classified into four categories as follows:

- *Energy efficient technologies*

Development of new technologies that reduce energy use as well as improving efficiency, production capacity and reliability has been more highlighted since shortage of energy sources has recently become more crucial. Today, numerous efficient technologies are employed by the factories throughout the world. Some of which are efficient transport systems, high-efficiency roller mills, utilizing high efficiency classifiers, high pressure roller press, multi-stage preheater with precalciner, reciprocating great coolers, high efficiency motors, adjustable speed drives, and improved refractories [7-15].

- *Product and feedstock modification*

Composition of raw materials and final product may directly influence on energy use. As shown in Figure.1 after crushing, preblending and grinding raw materials, they are calcined to produce the clinker. This calcination consumes between 24% of electrical and 38% of thermal energy used throughout a typical cement factory [1,16]. Reasonably, decreasing clinker-to-cement ratio will conserve a notable amount of energy. This might be achieved due to using clinker substitutes such as blast furnace and pozzolan [8]. Producing low alkali cements and limestone cements are other solutions to save thermal energy [7, 17].

- *Alternative fuels and recovering energy measures*

Conventionally, coal and petro coke are the most common fuels in cement plants [18]. Since these fossil resources are precious and hardly renewable, using alternative fuels that might be justified are identified as [19]:

1. The first are gaseous alternative fuels such as refinery waste gases and landfill gases.
2. The second are liquid alternative fuels, e.g. hydraulic oils.
3. The third includes pulverized and granulated solid alternative fuels, such as sawdust and granulated plastic.
4. The fourth category encompasses coarse-crushed solid alternative fuels, like crushed tiers.
5. The last is lump alternative fuels such as plastic bales.

Moreover, chemical reactions in producing clinker require very high heat, up to 1500 °c supplied by kiln burner [16]. A remarkable amount of the heat wastes in the cooler and or released to the air from the stacks [20]. Recovering this wasted heat to reuse or to produce electricity may ensure a considerable potential energy savings [21-23].

- *CO_2 emission reduction systems*

Although almost all of the energy efficiency measures implicitly help reduction of CO2 emission but certain measures have been implemented specifically to moderate GHG (Green House Gases) [24]. Most of these measures such as CCS (Carbon Capture and Storage) are not necessarily cost effective unless in the countries with penalties for producing GHG [25].

Most of the studies on energy efficiency, considered these measures discretely. In the literature, the emphasis is on technical characteristics: process specification, capacity enhancement, energy savings, CO_2 emission reduction and quality increase have been focused on each measure. In a comprehensive study, Worrell et al. gathered and classified energy efficiency measures for cement production [26]. In their study, some quantitative indicators are identified such as required cost, payback period as well as energy savings and CO_2 emission reduction amount. In the same way, specifications of efficient technologies were also reviewed by others [2, 16, 27] Specially emerging energy efficiency and CO_2 emission reduction technologies for cement and concrete production were discussed by Hassanbeigi et al. in 2012, mentioning commercial status of technologies such as research, development, pilot, demo and semi-commercial [24].

Moreover, by means of benchmarking techniques, some researches were performed to identify energy saving opportunities of cement industry in different countries [1, 28-30]. Utilizing EII (Energy Intensity Index) that compares the current situation of a plant with best practices, potential energy savings have been evaluated in some case studies [30, 31]. Energy efficiency measures were also sorted using both CSC (Conservation Supply Curve) and economic analysis [32]. As a different approach, eco-efficiency of some typical cement plants has been investigated employing DEA (Data Envelopment analysis) and directional distance function approach [33, 34].

2. Problem definition

Despite of these extensive studies, there is still a lack of comprehensive and integrated model to systematically evaluate and prioritize energy efficiency measures. Although, many researchers have attempted to rank measures by some limited criteria such as energy savings, investing cost and payback period, these evaluations overlook the current condition of a plant. Moreover, these methods mainly ignored some significant factors influencing the energy consumption.

As shown in figure 2, there are some parameters impacting prioritizing appropriate energy efficiency measures. At first, the desired objectives need to clearly be determined. In the case of cement plants, managers often set a target value in energy consumption and or CO2 emission per ton of cement produced. Decision making criteria should be also prescribed in the next step.

As an important fact, both qualitative and quantitative criteria should be considered simultaneously. Ease of implementation, knowledge and technology transfer consideration and adaptability with current equipment and operator's skill to conduct energy efficiency measures should be taken into account. In addition, some significant quantitative criteria for decision makers have not been discussed yet such as interruption time in implementation phase. Budgetary and time constraints as well as restrictions on economic indicators are most known constraints in energy saving projects. Also decision making techniques and managerial tools might be utilized in prioritizing energy efficiency measures.

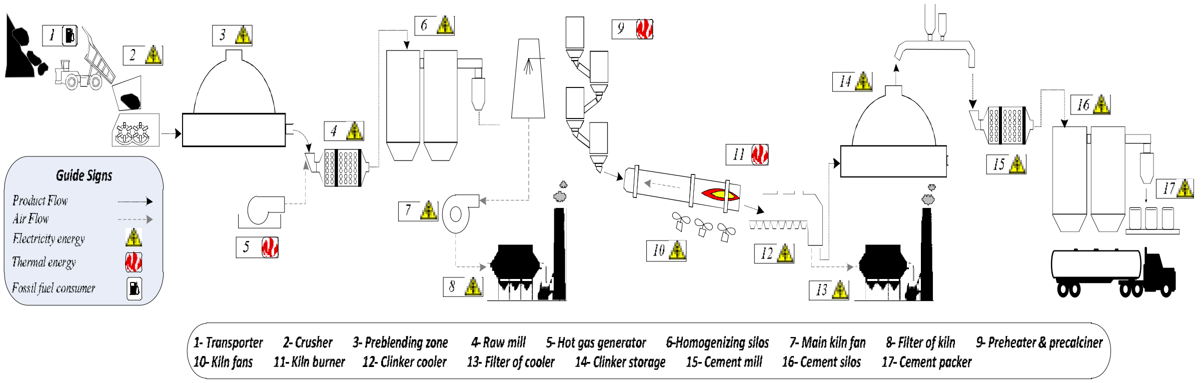


Figure 1: Energy consumer flow diagram of cement manufacturing.

In summary, prioritizing energy efficiency measures is a multi-criteria problem that conflicting constraints and the availability of numerous measures make it even more complicated.

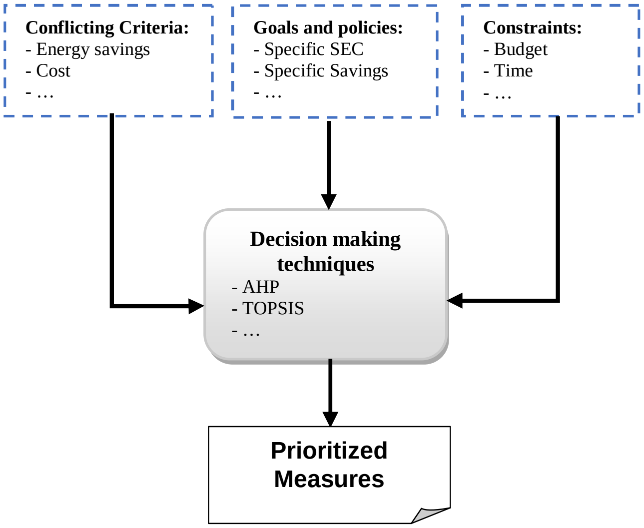


Figure 2: Decision making scheme for prioritizing the measures.

In this study, a comprehensive model is developed for prioritizing the energy efficiency measures. Goals and policies, both quantitative and qualitative criteria, constraints and decision making techniques are dealt with as well as the current plant conditions and technical limitations. The logic of the model is based on receiving required data as input from a real cement factory and representing the results in the form of prioritized measures to be recommended for the corresponding plant.

3. Methodology

The proposed model is designed in three phases (Figure.3). At the beginning, factors affecting energy consumption in a typical cement production plant are to be recognized. According to the identified factors and using an Energy Efficiency Measures Data Base (EEMDB), a list of feasible technologies will be generated.

Then energy efficiency opportunities are represented to stakeholders (i.e. decision makers). It shows how the energy consumption is different in the corresponding plant from the available benchmarks. Other than, total potential energy savings, potential CO_2 emission reduction, cost estimation of all feasible measures, operation and maintenance situation etc. will be listed.

In the second phase, policies and goals are to be defined by the stakeholders. Two kinds of policy are to be considered: improving efficiency of existing equipment and implementing new measures and technologies. Afterward, stakeholders will specify decision making criteria as well as budgetary and time constraints and their financial expectation. Taking these considerations through decision making techniques (a combination of AHP (Analytical Hierarchy Process) and TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution)), results in prioritizing energy efficiency measures.

EEMDB, the database, contains technical and economic data of energy efficiency measures collected from analogous projects in different countries. Since the model will be employed for a certain plant with its own internal and external circumstances, to enhance the accuracy of the results, EEMDB should be developed using domestic data. According to this fact that the model is in developing stage and its database should be evolved, we add the third phase to ensure the validity of the second phase outputs. In this phase, applicability of the selected measures is investigated from managerial point of view. Detailed economic evaluation is carried out for top priority measures. In ideal stage of the model when it uses a completed database, economic evaluation in the third phase could be skipped.
Detailed descriptions of the phases are as follow:

3.1 Phase one

In general, the required data in this phase come in two types: One for monitoring the current state of the plant and the other for determining the applicability of energy efficiency measures. For the sake of delivering these outputs, several influential factors should be investigated.

- Current condition

Annual production capacity, age of the plant in years, the current Electrical and Thermal Specific Energy Consumption (ESEC and TSEC), CO_2 emission per ton of cement production and must be available. These are mainly to prepare the energy relevant indicators and further comparisons.

- Raw materials and product properties

Raw material specifications such as humidity, hardness of raw materials and limestone dimension could directly influence on energy use. Materials with more humidity, more hardness and larger dimension use more energy in production processes [1]. Furthermore, in the final cement composition, percentage of clinker in the cement called clinker-to-cement ratio, remarkably change the amount of required thermal energy. Also alkali rate of the final product affects energy use. Burning the clinker with lower alkali rate consumes less thermal energy. Assessment of this rate is performed at this stage. Raw material and fuel prices are to be considered too

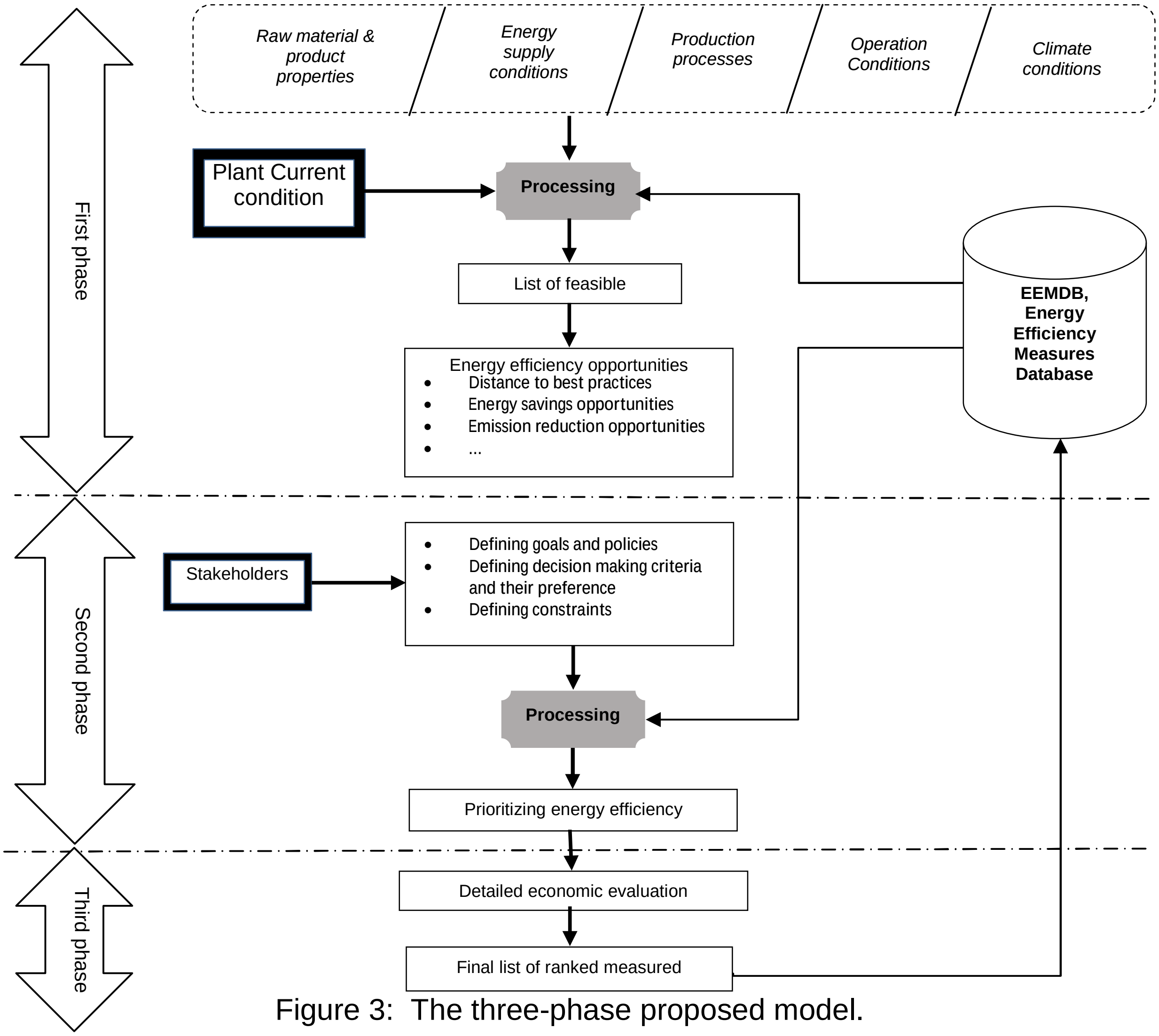


Figure 3: The three-phase proposed model.

- Energy supply conditions

All kinds of fuel currently employed in the plant are to be specified. New alternative fuels could be suggested by the model as possible energy efficiency measures. This suggestion will be based on the evaluation of some variables such as fuel purchase price, operating costs, the attributed CO2 emission fines, shifting cost from one fuel to the other, interruption time and probable lost sale. If energy managers encounter changing issue from the current fuel to other alternative fuels, the following evaluation is performed in the model:

Total cost of current fuel ≈ Total cost of alternative fuel + shifting cost + lost sale (1)

$$[(A_{cf} \times P_{cf}) + OC_{af} + (E_{cf} \times PF)] \times C \times D \approx [(A_{af} \times P_{af}) + OC_{af} + (E_{af} \times PF)] \times C \times D + CS_{cf\ to\ af} + D_i \times C \times P_c$$

Where:

A_{cf} : *Amount of current fuel required for producing one ton of cement (m3, liter or kg)*

P_{cf} : *Unit price of current fuel* ($)

OC_{cf} : *Operating cost of current fuel to produce one ton of cement*($)

E_{cf} : *Emission released to the atmosphere for producing one ton of cement using current fuel (kg)*

PF : *Pollution fines for producing a kilogram of emission* ($)

C : *Plant capacity (tones of cement per day)*

D : *Duration of using alternative fuel (day)*

A_{af} : *Amount of alternative fuel required for producing one ton of cement (m3, liter or kg)*

P_{af} : *Unit price of alternative fuel* ($)

OC_{af} : *Operating cost of alternativefuel to produce one ton of cement* ($)

E_{af} : *Emission released to the atmosphere for producing one ton of cement using alternative fuel (kg)*

$CS_{cf\ to\ af}$: *Cost of shifing from current fuel to alternative fuel*

D_i : *Duration of interuption time for shifting from current to alternative fuel (day)*

P_c : *Cement sale* ($/*ton*)

For a given duration of D, if the left side of the above relation is more than the right side, shifting from current fuel to a new alternative fuel becomes cost effective.

•*Production processes and consumption*

The dominant factors that determine whether or not an energy efficiency measure is feasible in a plant are production processes. If production processes in each cement department use out of date and inefficient technologies, more energy efficiency measures will applicable in the plant. The model requires the initial data about processes and technologies such as crushing, transporting, homogenizing, grinding, pyro processing as well as process control systems, compressed air system, refractory type, type of drives, lighting system etc. Moreover, the energy consumption of each department should be accessible for comparison with best practices.

•*Operation condition*

For assessing and determining the efficiency of equipment, several significant factors should be considered: Percentage of elapsed lifetime, maintenance level, nominal capacity, percentage of working hours per day, humidity, temperature and the amount of dust in the working area as well as actual capacity, time and duration of stoppage and emission rate.

•*Climate conditions*
It has been technically proved that some climate conditions influence on energy consumption [35]. For instance, the more is the altitude of the factory above the see level, the more air pressure drop occurs in the preheater cyclones which lead to higher electrical consumption in the main kiln fan.

EEMDB contents attributed to energy efficiency measures complement with: amount of electrical and thermal energy savings, CO_2 emission reduction, investment needed, operating costs, payback period, project duration are brought in as well as some qualitative data such as ease of implementation, knowledge and technology transfer, adaptability with current equipment and skill of operators to conduct measures. For each measure, these qualitative criteria might be valued from 0 to 10 scales by experts. After receiving explained input data, the model investigates all measures in EEMDB in compliance with plant conditions and processes to determine their applicability. Then a list of feasible measures will be released. In addition, some monitoring reports are represented to stakeholders to depict current situation of the plant. These outputs encompass Energy Intensity Index, detailed differences with best practices and available standards, number of feasible measures, total potential electrical and thermal energy savings, possible CO_2 emission reduction, overall operation and maintenance level etc.

3.2 Phase two

At first, policies and goals along with managerial constraints and preference of criteria should be determined by the stakeholders. Two kinds of policy could be pursued in the model: enhancing efficiency by keeping current processes and technologies and improving processes implementing energy efficiency projects. In the former, poor efficient processes and equipment will be considered to improve their efficiency using corrective actions or replacement. It is remarkable that in addition to nominal and actual capacity, some additional parameters affect identifying inefficient equipment such as percentage of elapsed lifetime, maintenance level, percentage of working hours per day, humidity, temperature and the amount of dust in working area. In the latter policy, the model will acquire other parameters. In most cases, goals are defined so that they reach to specified amount of SEC or reduce energy consumption and CO_2 emission in a defined timeframe.

Then, budgetary constraints and expected payback period as well as possible limitations in the project duration and production stoppage are given by the stakeholders. Ten qualitative and quantitative criteria to prioritize feasible measures via decision making technique are imbedded in the model.

The model proposed a combination of AHP and TOPSIS as decision making techniques. Regarding to the variety of criteria and their inherent differences, it would be more convenient to contrast and weighting criteria in a pair-wise comparison using AHP.

After weighting criteria by the stakeholders, all feasible measures delineated in the first phase are examined to investigate whether they meet the restrictions. Measures that don not comply the limitations, be ignored. The remaining ones are prioritized via TOPSIS. Since often we have multi different criteria with numerous feasible measures that have diverse characteristics in criteria, TOPSIS is chosen to solve this multi-criteria problem. The prioritized feasible measures will be extracted considering their normalized differences with positive and negative ideal measures.

Along with the prioritized measures, some beneficial reports could be presented to the stakeholders answering some of their critical inquires: by implementing which measures, their desired goals will be satisfied? How much budget do these measures require? How much energy savings could be acquired executing these measures? How energy indexes will be eventually ameliorated?

3.3 Phase three

In this phase, each prioritized measure is surveyed to examine their applicability. For instance, suppose that in a specific plant, using vertical roller mill instead of ball mill for cement grinding ranked as the first precedence measure. But at the same time, the plant has a huge clinker inventory and could not stop producing cement to implement the measure in this segment of the process. So this project has incoherence with current conditions and should be discovered from the selected measures.

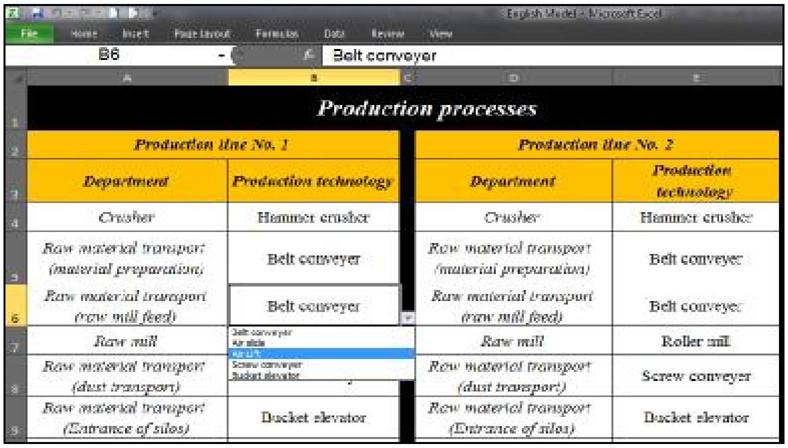
In the final phase of the model, top priority measures that meet practical constraints are investigated as economic point of view. A detailed economic evaluation is carried out for each selected measures. Since economic data of measures which is already in EEMDB is gathered by identical projects from different countries around the world, it should be evaluated by local conditions to ensure the accuracy of the final results. It is accomplished by determining some economic indicators such as Rate of Return (ROR), Payback Period (PP), and Present Value (PV). The following section explains how the model is physically implemented.

4. Implementation

The model has been implemented using spread sheet software (MS Excel). It has been formulated in a manner that by entering the required inputs, the results and the reports will be shown automatically. The file could be used for factories with maximum 6 cement production lines. At the beginning, the data is captured and presented in 24 sheets including but are not limited to:

- General factory information, cement and clinker capacity for each production line, plant age, current electrical and thermal SEC, amount of CO2 emission.
- Portion of raw material ingredients, their friction coefficient, humidity, average dimension, final cement composition, alkali rate.
- Current applied fuel, fuel information such as required amount for producing one ton of cement, purchase and operation costs, related amount of emission, shifting costs between current fuels to possible alternative fuels

- Technologies used for production processes (as partly shown in Figure 4). It is encompasses all work areas, departments and utilities applied to produce cement and clinker.



Production processes			
Production line No. 1		**Production line No. 2**	
Department	***Production technology***	***Department***	***Production technology***
Crusher	Hammer crusher	*Crusher*	Hammer crusher
Raw material transport (material preparation)	Belt conveyer	*Raw material transport (material preparation)*	Belt conveyer
Raw material transport (raw mill feed)	Belt conveyer	*Raw material transport (raw mill feed)*	Belt conveyer
Raw mill		*Raw mill*	Roller mill
Raw material transport (dust transport)		*Raw material transport (dust transport)*	Screw conveyer
Raw material transport (Entrance of silos)	Bucket elevator	*Raw material transport (Entrance of silos)*	Bucket elevator

Figure 4: Table of production process information

- Detailed thermal and electrical energy consumption, producing energy using low and high temperature heat recovery.
- Equipment data such as, equipment code, percentage of elapsed useful life, nominal and actual capacity if any, operation conditions and maintenance level.
- Climate conditions including altitude and ambiance average humidity and temperature.

The model initially processes the inputs to identify energy efficiency opportunities using comparisons with best practices available standard. As shown in Figure 5, detail comparison reveals variances between current energy consumption and best practices in the defined processes. Total electrical and thermal energy savings as well as total emission reduction opportunities are calculated. Furthermore, inefficient equipment is identified considering operation conditions mentioned in section 3.1.

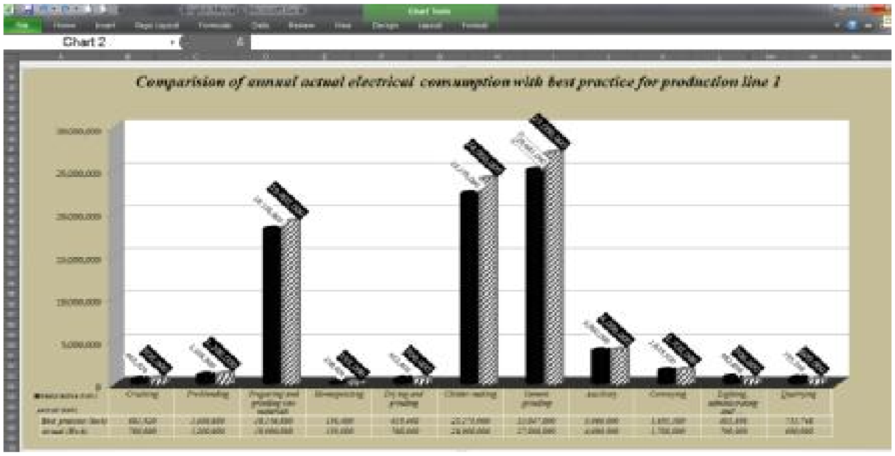
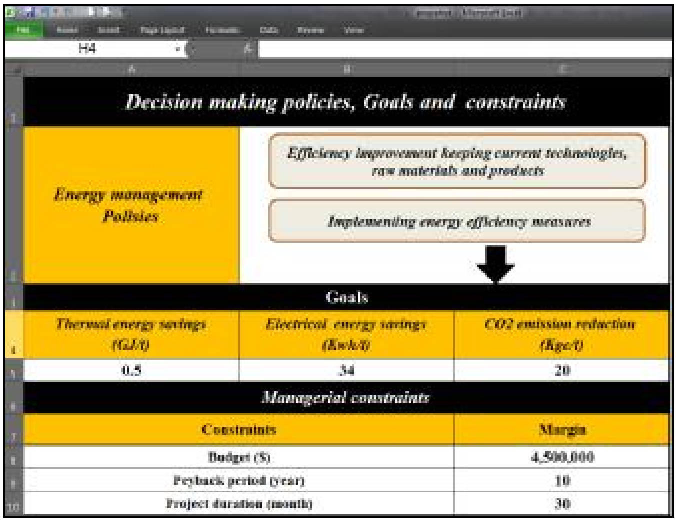


Figure 5: Energy efficiency opportunities chart.

Afterwards, energy management policy is adopted. As discussed before, two different policies could be considered: Improving the efficiency by keeping the current technology, materials and products and or implementing energy efficiency measures by alteration in technology, raw materials and final product. As shown in Figure 6, the sheet acquires electrical and thermal targeted savings as well as amount of required CO2 emission reduction. Decision making constraints such as time and budget limitations are identified as well.



Decision making policies, Goals and constraints

Energy management Polisies

- *Efficiency improvement keeping current technologies, raw materials and products*
- *Implementing energy efficiency measures*

Goals

Thermal energy savings (GJ/t)	*Electrical energy savings (Kwh/t)*	*CO2 emission reduction (Kge/t)*
0.5	34	20

Managerial constraints

Constraints	Margin
Budget ($)	4,500,000
Peyback period (year)	10
Project duration (month)	30

Figure 6: energy policies, goals and constraints setup sheet.

If managers prefer to choose the first policy, the model gives the possibility of recognizing inefficient equipment and departments. Efficiency of equipment acquired dividing actual capacity/power to nominal capacity/power considering some allowances for percentage of elapsed life time, working environment and maintenance conditions. As shown in Figure 7, departments could be sorted by their efficiencies to identify inefficient departments for managers to peruse the corrective actions or replacing tasks.

If second policy i.e. implementing energy efficiency measures is taken, the comparative preference of criteria should be determined by decision makers.

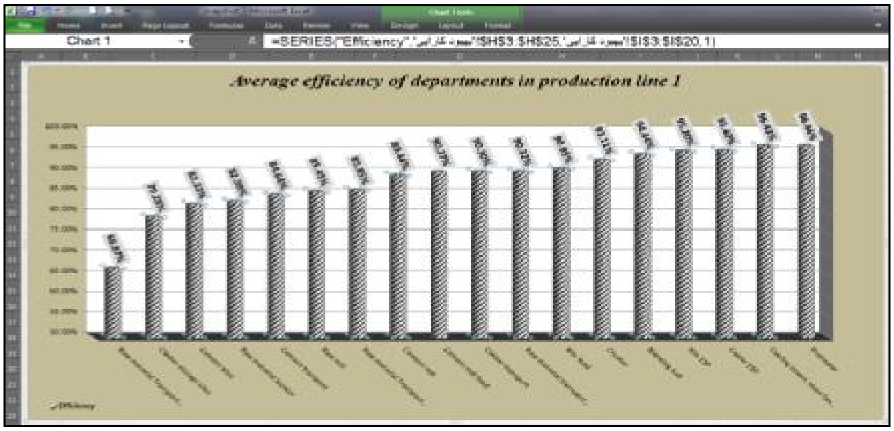


Figure 7: Average efficiency of departments chart.

A pair-wise matrix is designed employing comparison expressions for convenience of decision makers. These expressions are converted into 1/9 to 9 ranges of digits for further calculations.

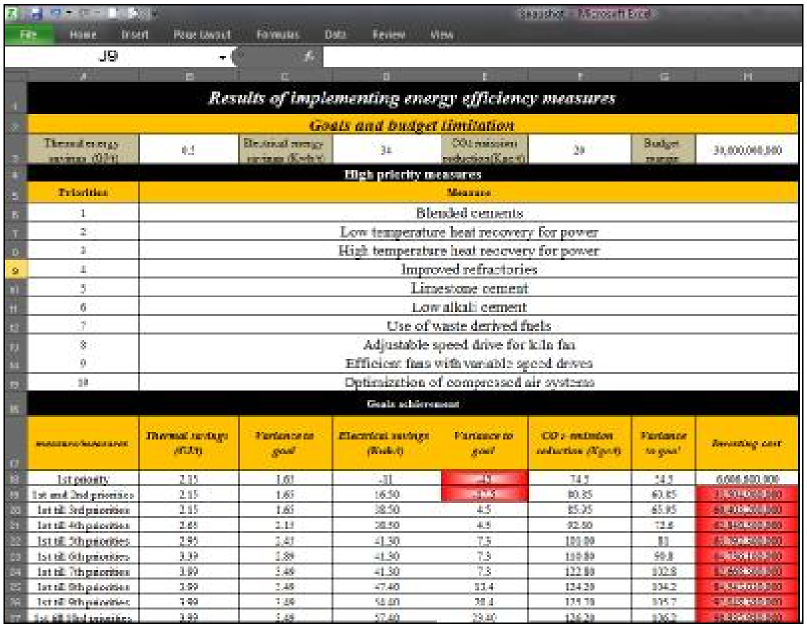
Applying criteria, weight factors extracted from the matrix, remaining measures are prioritized using TOPSIS method described in section 3.2. Illustrated by Figure 8, the final results of implementing the suggested measures could be evaluated in accordance with the pre-defined objectives and constraints. Potential cumulative thermal and electrical energy savings and CO2 emission reduction are estimated and the deviation from the target values are represented.

An economic evaluation is performed for top rank measures incorporating some significant economic indexes such as net present value, payback period and rate of return.

The database and input sheets are well linked and integrated so that any single modification in a cell affects the entire data process and outputs.

5. Conclusions

Prioritizing and selecting the appropriate energy efficiency measures has been introduced and discussed as a multi-criteria and multi-alternative decision making problem. All affecting parameters such as policies, goals, qualitative and quantitative criteria and constraints were applied in three phases of a comprehensive model to prioritize the alternative measures via a combination of AHP and TOPSIS as decision making techniques. The proposed scientific model has been developed in a



Results of implementing energy efficiency measures

Goals and budget limitation

Thermal energy savings (GJ/t)	0.5	Electrical energy savings (Kwh/t)	34	CO2 emission reduction(Kg/t)	20	Budget margin	30,000,000,000

High priority measures

Priorities	Measures
1	Blended cements
2	Low temperature heat recovery for power
3	High temperature heat recovery for power
4	Improved refractories
5	Limestone cement
6	Low alkali cement
7	Use of waste derived fuels
8	Adjustable speed drive for kiln fan
9	Efficient fans with variable speed drives
10	Optimization of compressed air systems

Goals achievement

[illegible]	Thermal savings (GJ/t)	Variance to goal	Electrical savings (Kwh/t)	Variance to goal	CO2 emission reduction (Kg/t)	Variance to goal	Investing cost
1st priority	2.15	1.65	-31	[illegible]	74.5	54.5	6,600,000,000
1st and 2nd priorities	2.15	1.65	16.50	[illegible]	80.85	60.85	[illegible]
1st till 3rd priorities	2.15	1.65	38.50	4.5	85.35	65.85	[illegible]
1st till 4th priorities	2.65	2.15	38.50	4.5	92.50	72.6	[illegible]
1st till 5th priorities	2.95	2.45	41.30	7.3	101.00	81	[illegible]
1st till 6th priorities	3.39	2.89	41.30	7.3	110.80	90.8	[illegible]
1st till 7th priorities	3.99	3.49	41.30	7.3	122.80	102.8	[illegible]
1st till 8th priorities	3.99	3.49	47.40	13.4	124.20	104.2	[illegible]
1st till 9th priorities	3.99	3.49	54.40	20.4	135.70	115.7	[illegible]
1st till 10th priorities	3.99	3.49	57.40	23.40	126.20	106.2	[illegible]

Figure 8: The final result sheet.

practical point of view as it deals with the real technical and financial conditions of a plant. Due to this fact, cement factory owners and energy managers may directly employ this application to support their decision making and optimize their selection. However, to enhance the applicability and accuracy of the outputs, the EEMDB needs to be developed trying the model for numerous real cases. Last but not least, to make the application more user-friendly, utilizing a higher level of computer programming and developing a more professional GUI is inevitable.

References

[1] Avami A, Sattari S. Energy conservation opportunities: Cement industry in Iran. International Journal of energy. 2007; vol.1.no. 3:65-71.
[2] Madlool NA, Saidur R, Rahim NA, Kamalisarvestani M. An overview of energy savings measures for cement industries. Renewable and Sustainable Energy Reviews. 2013;19:18-29.
[3] Jankovic A, Walter V, Eugene D. Cement grinding optimization. Mineral engineering. 2004;17, pp. 1075-81.
[4] onlineconversion. [Online]. Available: http://www.onlineconversion.com/energy.htm. [Accessed 22 08 2013].
[5] WBCSD. Cement Sustainability Initiative: Cement Industry Energy and CO2 performance. Gettingthe Numbers Right. Geneva and Washington DC. World Business Council for Sustainable Developmen. 2009. [Online]. Available: http://www.wbcsd.org/DocRoot/IV5ZFD9dESJoSb3h7kxM/csi-gnrreport-withlabel.pdfS.
[6] U. G. survey. mineral commodity summerized 2013. U.S. Geological survey. 2013.
[7] Holderbank. Present and future energy use of energy in cement and concrete industries in Canada. Ottawa; Ontario; Canada; 1993.
[8] Cembureau. Best available techniques for the cement industry. Brussels; 1997.
[9] Sussegger A. Modern roller press technology. Seprator-report'92 Proc. KHD Symposium'92, KHD Humbuldt Wedag. Cologne; Germany; 1993.
[10] Seebach HM, Neumann E, Lohnherr L.State-of-the-art of energy-efficiency grinding systems. ZKG International. 1996;2.61-67.
[11] Sauli R .Rotary kiln modernization and clinker production increase at Testi cement plant of S.A.C.C.I. Spa. Italy Proc. KHD Symposium'92, KHD Humbuldt Wedag. Cologne; Germany; 1993.
[12] Vleuten F. Cement in development: energy and environment. Netherlands energy research foundation; Petten, the Netherlands; 1994.
[13] Fujimoto .Modern technology impact on power usage in cement plants. 35th IEEE cement industry technical conference, Toronto; Ontario; Canada; 1993.
[14] Plessis GED, Liebenberg L, Mathews EH. The use of variable speed drives for cost-effective energy savings in South African mine cooling systems. Applied Energy. 2013; 111:16-27.
[15] ITIBMIC.Final report on cement survey. Prepared for the United Nations Industrial Development Organization (UNIDO) for the contract entitled cement sub-sector Survey for the project energy conservation and GHG emission reduction in Chinese TVEs-phase2. Contract no. 03/032/ML, P.O. No. 16000393; 2004.

[16] Madlool NA, Saidur R, Hossain MS, Rahim NA. A critical review on energy use and savings in the cement industries. Renewable and sustainable energy reviews. 2011; 15:2042-2060.
[17] Detwiler RJ, Tennis PD.The use of limestone in Portland cement: A state-of-the-art review. Portland cement association; 1996.
[18] OECD. IEA. The World Business Council for Sustainable Development-WBCSD.Cement technology roadmap 2009; 2009.
[19] Mokrzycki E, Uliasz-Bochenczyk A, Sarna M. Alternative fuels for the cement Industry. Applied Energy.2003;74: 95-100.
[20] .Energy efficiency Asia 2010. [Online]. Available: http://www.energyefficiencyasia.org/docs/IndustrySectorCement_draftMay05.pdf. [Accessed 20 08 2010].
[21] A. N. c. plant. The report of power generation by waste heat of the kiln in Ningguo Cements Plant. http://green.cei.gov.cn/doc/LY31/200204192475.htm;2002.
[22] Steinbliss E. Traditional and advanced concepts of waste heat recovery in cement plants energy efficiency in the cement industry (Ed. J. Sirchis), England, London: Elsevier Applied Science;1990.
[23] Saneipoor P, Naterer GF, Dincer I.Heat recovery from a cement plant with a Marnoch Heat Engine. Applied Thermal engineering.2011; 31: 1734-1743.
[24] Hasanbeigi A, Price L, Lin E. Emerging energy efficiency and CO2 emission-reduction technologies for cement and concrete production: A technical review. Renewable and Sustainable Energy Reviews.2012; 16: 6220-6238.
[25] Moya JA, Pardo N, Mercier A. The potential for the improvements in energy efficiency and CO2 emission in the EU27 cement industry and relationship with the capital budgeting decision criteria. Journal of Cleaner Production. 2011; 19: 1207-1215.
[26] Worrell E, Galitsk C, Price L. Energy efficiency improvement opportunities for the cement industry. Environmental Energy Technologies Division Lawrence Berkeley National Laboratory; 2008.
[27] Worrell E, Galitsky C.Energy efficiency improvement and cost saving Opportunities for cement making. Environmental Energy Technologies Division Ernest Orlando Lawrence Berkeley National Laboratory University of California, California, Berkeley; 2008.
[28] Phylipsen D, Blok K, Worrell V, Beer JD.Benchmarking the energy efficiency of Dutch industry: an assessment of the expected effect on energy consumption and CO2 emissions. Energy Policy. 2002; 30: 663-679.
[29] Saidur R, Sambandam MT, Hasanuzzaman M, Devaraj D, Rajakarunakaran S. An analysis of actual energy savings in an Indian cement industry through an energy efficiency index. International Journal of Green Energy.2012; 9: 829-840.
[30] Hasanbeigi A, Price L, Lu H, Lan W.Analysis of energy efficiency opportunities for the cement industry in Shandong province, China: A case study of 16 cement plants. Energy.2010; 35: 3461-3473.
[31] Price L, Hasanbeigi A, Lu H.Analysis of energy-efficiency opportunities for the cement industry in Shandong province, China. China Energy Group; Energy Analysis Department; Environmental Energy Technologies Division Lawrence Berkeley National Laboratory. California; Berkeley; 2009.

[32] Hasanbeigi A, Menke C, Therdyothin A. The use of conservation supply curves in energy policy and economic analysis: The case study of Thai cement industry. Energy Policy.2010; 38: 392-405.
[33] Oggioni G, Riccardi R, Toninelli R.Eco-efficiency of the world cement industry: A data envelopment analysis. Energy Policy. 2011; 39: 2842-2854.
[34] Riccardi R, Oggioni G, Toninelli R.Efficiency analysis of world cement industry in presence of undesirable output: Application of data envelopment analysis and directional distance function. Energy Policy.2012; 44: 140-152.
[35] ISIRI, Standard of Cement- Energy consumption indices in production processes, Iran; Tehran; ISIRI; 2011.