Scenario analysis of the potential for CO_2 emission reduction in the Iranian cement industry

Farideh Atabi [1,*], Mohammad Sadegh Ahadi [2], Kiandokht Bahramian [3]

[1*]Assistant Prof., Graduate School of Energy and the Environment, Science & Research Branch, Islamic Azad University, Tehran, Iran, P.O.Box: 14155/4933
[2] National Climate Change Office, Department of Environment, Tehran, Iran
[3]Environmental Engineer, Graduate School of Energy and the Environment, Science & Research Branch, Islamic Azad University, Tehran, Iran
* Corresponding author. Tel: +989121341702, E-mail: far-atabi@jamejam.net

Abstract: This article investigates the impact of various policies on the reduction of CO2 emissions from Iranian cement industry using a long range energy alternative planning (LEAP) model. A Business-as-Usual (BAU) scenario for the existing Iranian cement industry was applied. Moreover, the current and future demands for the cement industry were defined for 2005-2020. The current and future productivity of the cement industry was predicted in the BAU scenario. Then, three alternative scenarios were considered: replacement of heavy oil with natural gas, implementation of energy efficiency policies and integrated emission reduction, which includes all of the options over a 15-year period. The results indicated that in 2020, CO2 equivalent emissions would reach 61 million tons in the baseline scenario and 53 million tons in the integrated emission reduction scenario. If fuel switching were employed, the emissions would reach 58 million tons (4.9 % reduction) and in the energy efficiency scenario, the emissions would reach 55 million tons (9.8% reduction) in 2020. Therefore, the integrated scenario reduces the total CO2 equivalent emissions by 8 million tons (13% emission reduction).

Keywords: *CO_2 emission, cement industry, scenario analysis, energy model*

1. Introduction

Even though many countries have started to develop climate policies, scenario studies indicate that greenhouse gas emissions are likely to increase in the future in most regions around the world [1]. After the energy crisis of the 1970s, many researchers developed models to generate accurate predictions. Various models for prediction and the development of policies for mitigation can be divided into two groups: those used for mitigation in the energy sector, and those used to survey mitigation methods in the agriculture, forest and land use sectors [2]. One of the most important energy carriers in the industrial sector is natural gas, which plays a significant role in the reduction in the emission of environmental pollutants [3]. A study in Iran, evaluated the impacts of price reform and energy efficiency programs on the consumption of energy carriers and on GHG mitigation in the Iranian residential buildings sector using the LEAP model [4]. Research on substituting biomass with other energy carriers in Vietnam using the LEAP model, has shown that this fuel substitution leads to a 10.83 million-ton reduction in GHG emissions [5].

Another analysis of the environmental and economic impact of landfill gases (LFG) electricity generation in Korea using the LEAP model showed that LFG electricity generation would be an effective solution for CO_2 displacement over the medium term with additional energy profits and will reduce the global warming potential by a maximum of 75% when compared to spontaneous emissions of CH_4 [6]. Another study in Korea evaluated the environmental and economic aspects of chemical CO_2 absorption in power plants using this model; That study demonstrated that by applying various policies, the rate of CO_2 emissions will decrease by approximately 15% by 2014 [7]. Another study was also conducted to show the potential reduction in CO_2 emissions from oil refineries in Korea. Production analysis using the energy planning model showed that a 48% reduction in CO_2 emissions is feasible [8]. In this study, the energy demand of the Iranian cement industry is analysed with an energy planning LEAP model. The effects of various policies on the baseline scenario and GHG mitigation scenario are also analysed and surveyed in the cement industry.

2. Methodology

Greenhouse gas emissions in the Iranian cement industry was surveyed in the format of a BAU scenario using the LEAP energy planning model. The results of employing different policies of energy efficiency and fuel switching on GHG mitigation in the format of mitigation scenario were then observed. Finally, the effectiveness of each policy applied in the cement industry over a 15-year period, from 2005 to 2020, was surveyed. In each scenario, the level of technological activity and energy intensity were specified, and in the activity data section, data relevant to consumption in the cement industry and the number of factories that use a specific resource, were defined in each scenario. Additionally, data describing the energy intensity of each type of fuel in each Factory were determined [9].

2.1. LEAP model

LEAP is an energy planning model that consists of an end-use structural model. Based on procedural analysis of the supply and demand network, the considered model describes technological energy carrier utilisation based on energy demand on one hand, and technological changes and therefore structural changes and efficiency of energy conversion systems as well as the rate and type of available primary energy resources on the other hand. This model consists of a hierarchical structure in which energy flows from the last point of usage (equipment and technology) toward higher levels. In fact, total energy demand is computed from each subcategory and category in a tree structure. In this model, the rate of total energy demand is computed according to Eq. 1.

$$\sum E_t = T_i \times I_i \qquad (1)$$

where, E_t is the total energy demand (J), T_i is the data (i) activity level (ton), and I_i is energy intensity (j/ton) [6].

2.2. BAU scenario

In the (BAU) scenario, it is assumed that the current status of the Iranian cement industry will be maintained in the future, and that greenhouse gas emission in Iran's cement industry will be predicted by the main variables of BAU, such as the growth rate of cement production from 2005 to 2020, the type and rate of fuel consumption, the rate of technological changes and energy intensity.

In this scenario, 2005 was selected as the base year and all relevant information was gathered from this year [10]. Then, a BAU scenario was developed according to current plans as well as future policies, changes in cement production capacity, energy intensity, the fuel contribution that supplies the energy demand and other factors in the cement industry from 2005 to 2020. The GHG emission rate was assessed, and analysed. It was predicted that in the BAU scenario, the natural gas share of the total energy carriers, will increase from 63.11% in 2005 to 80% in the 2020 in the cement industry [11]. The amount of energy intensity of the whole cement industry in the country can be calculated using Eq. 2:

$$I_t = \sum c_i I_i \quad (2)$$

where, I_t is total energy intensity (j), I_i is energy intensity of respected technology (J/ton), and c_i is the technology (i) share in the total cement production in the country (%).

Energy demand as shown in Eq. 3 is calculated by multiplying cement production (activity data) by energy intensity:

$$E = \sum_{i=1}^{n} A_i \times I_i \quad (3)$$

where, E is energy demand (million GJ), A_i is cement production (million tons), and I_i is energy consumption for each activity (million GJ/ton).

The LEAP model is used to calculate the equivalent emission of CO_2 in the cement industry in three forms: (1) emission from direct consumption of energy carriers in cement industry, (2) emission from consumption of energy carriers in oil and gas refineries and power plants in order to supply the cement industry with both fuel and electricity (indirect), and (3) emissions from consumption of energy carriers in the industry, refineries and power plants to supply the energy demand to the cement industry (total emission).

2.3. Mitigation scenario

In the mitigation scenario, different policies to mitigate the energy demand are considered as input data for the LEAP model. Then, the model is compared with the BAU scenario by predicting the demands of energy carriers and the calculated mitigation in emissions. The policies surveyed here are fuel switching and more energy efficient technologies. In this scenario, it is assumed that all cement production units older than 20 years are replaced with new and efficient technologies and that energy efficient improvement plans are implemented on units that are 10 to 20 years old [12]. It is also assumed that the natural gas and biomass share in the mitigation scenario is 5% more than that in the BAU scenario in 2020. Energy carrier demand will increase 139% in this period.

3. Results and discussion

In Table 1, the average energy intensity for Iran's cement industry was calculated and presented separately based on the type of process. In the calculations, the average energy intensity weight was compared to the capacity of the entire cement industry in the country.

Table1. Energy intensity rate in the various cement industry technologies in Iran in 2005 [13]

Technology	Proportion of Total Production (percent)	Production (ton/yr)	Capacity (ton/day)	Fuel Consumption Intensity (kcal/kg.clinker)	Electricity Consumption Intensity (kWh/ton)
Dry high heater	5.14	1,600,500	4,850	1125	111
Dry pre heater	40.51	12,606,000	38,200	950	108
Dry pre heater & precalcinors	51.70	16,087,500	48,750	890	114
Mid dry pre calciners	0.64	198,000	600	1020	110
Wet process	2.01	627,000	1,900	2000	150
Total / Weighted average	100	31,119,000	94,300	949.6	112.1

To evaluate the changes in energy intensity, in addition to recognizing current infrastructures in each of the subsectors of the industry, the theoretical potential for increasing the efficiency of equipment and energy intensity of industrial products in developed countries is also needed. In the BAU scenario, the annual increase in energy demand reaches 11.51% and the demand for all energy carriers shows an annual increase of 10.7%.

It is predicted that the share of natural gas in the BAU scenario among all energy carriers in this industry will increase from 63.11% in 2005 to 80% in 2020. Meanwhile, the mitigation scenario shows a 5% increase in 2020 compared to the BAU scenario in the same year. Results from LEAP in Fig. 1 show that in the BAU scenario, emissions of CH_4, CO_2 and NO_x have also increased during this period; CO_2 has the highest increase.

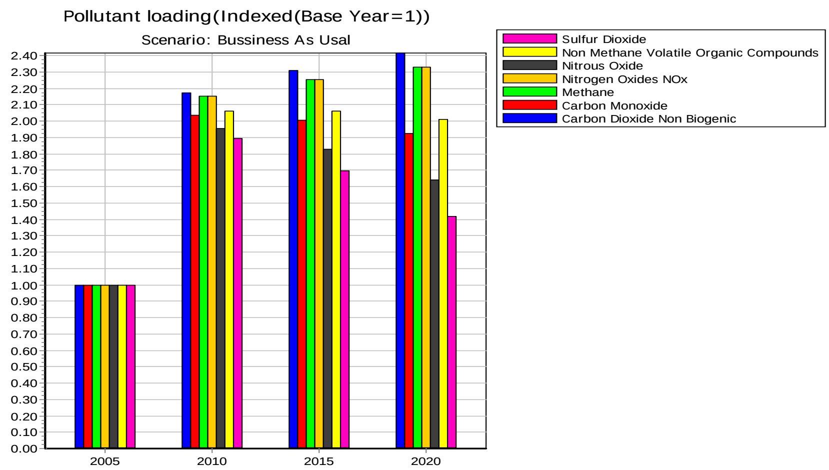

Fig.1. Prediction of the trends of the emission of pollutants and GHG (dimensionless) in the Iranian cement industry in the baseline scenario.

Meanwhile, the thermal energy demand in the mitigation scenario in 2020 shows a 33% reduction in the thermal energy demand compared to that of the BAU scenario. The emissions of all pollutants increase until 2010 and then decline because of the replacement of units that are older than 20 years with new and more efficient technologies. It should be noted that the emission of SO_2 and NO_x in 2020 are 40% and 10% less than the emission of these pollutants in the first year (2005) respectively, whereas, the emission of NO_x and SO_2 in the baseline scenario has increased by 40% and 65% , respectively. Therefore, after applying the emission reduction policies (mitigation scenario), the emissions of SO_2 and NO_x show 80% and 75% reduction in 2020 respectively, compare to those of the BAU scenario.Table 2. shows the energy carriers in the BAU scenario and the mitigation scenarios.

Table 2. Comparison among the different energy carriers, that are needed in the Iranian cement industry in the year 2020 in the BAU and mitigation scenarios

Fuel	Share of the total demand (%) 2005	Share of the total demand (%) 2020	
		Mitigation scenario	BAU Scenario
Fuel oil	36.1	9.21	19.3
Natural gas	63.11	85	80
Diesel fuel	0.79	0.79	0.79
Biomass	0	5	0

As shown in Fig. 2, by implementing the policy of changing the process on one hand and the energy efficiency on the other hand, the amount of required energy carriers decreased from 340 million GJ in 2020 to 310 million GJ, and consequently, energy demand decreased by 11.5 percent.

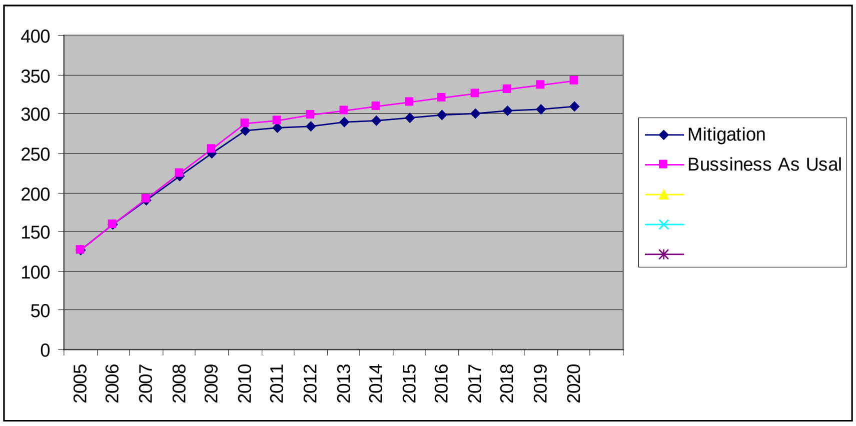

Fig. 2. Comparison of energy carriers demand in the baseline and mitigation scenarios in the Iranian cement industry (million GJ)

Results show that employing different policies regarding CO_2 emissions reduces these emissions from 16 million tons to 11 million tons in 2020. Fig. 3 shows a comparison of the CO_2 emissions in the BAU and mitigation scenarios in the Iranian cement industry.

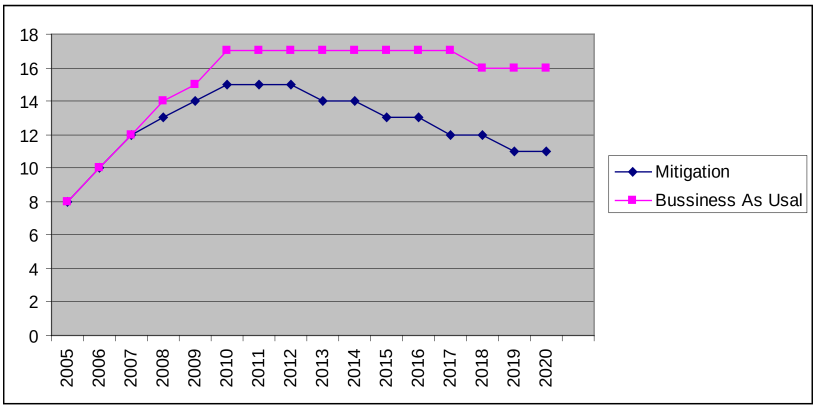

Fig.3. A comparison of CO2 emission in the BAU and mitigation scenarios in the Iranian cement industry (million tons).

As shown in Fig. 4, GHG emission (CO_2 equivalent) is reduced as a result of the efficiency policy and the fuel switching policy by 9.8% and 4.9%, respectively. However, emission reduction will be up to 13% by employing both policies**.**

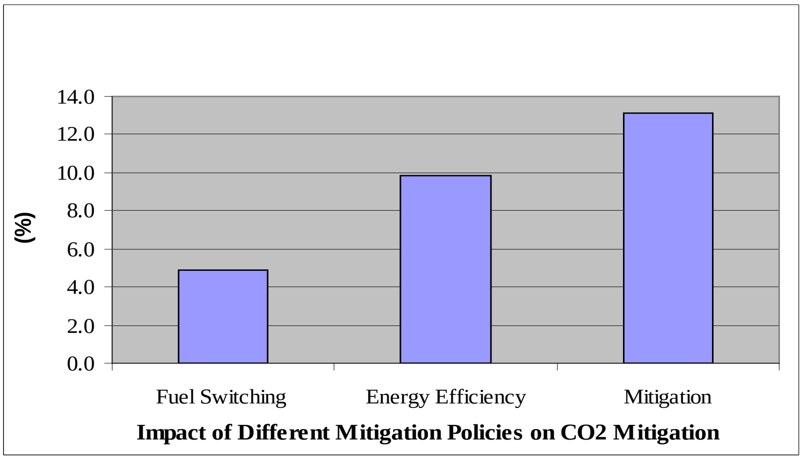

Fig. 4. Comparison of exerting different policies for GHGs (CO2 equivalent) reduction and integration of different scenarios in the Iranian cement industry

4. Conclusion

In this study, the process of technological changes that have improved the energy intensity in the Iranian cement industry specifically are used to predict the energy intensity in the BAU scenario and the mitigation scenario using LEAP software. To predict the greenhouse gas emissions rate in the different scenarios, the effects of the application of these actions on energy demand and fuel make-up are specified. A comparison of the effectiveness of different policies shows that the energy efficiency is more important than fuel switching in reducing CO_2 emissions.

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