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**Article**

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# Energy-environmental performance of Thai's cement industry

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## Abstract

One of the most important mechanisms to improve the sustainability of each country are monitoring the performance of the industries not only in the energy perspective but also the environmental point of view and setting the improvement goal. This study presents an indicator that can reflect both of energy consumption and greenhouse gas emission simultaneously called energy-environmental performance index. The cement industry is selected as the case study due to its important role in Thai's economic system and because it has high energy and greenhouse gas intensities. The performance of the sector during 2010–2016 are evaluated from the statistical data of volume produced, gross outputs in monetary value, energy consumption, raw material-to-clinker ratio, clinker-to-cement ratio and composition of clinker. The result shows that the energy-environmental performance index under the current situation of cement sector is 0.70. This is the average performance for the sector-level and can be used as the benchmarking for the company in the same industry. Since all data required for the calculation are the basic data for most companies, it means that the company can estimate its performance at the company level as well. Besides, this study also uses the statistical data and results in 2010–2016 to forecast the baseline performance in 2025 and then uses the baseline performance including target from the energy conservation plan and greenhouse gas mitigation plan to estimate the performance target. It could be found that the energy-environmental performance target of cement industry in 2025 is 0.75. © 2019 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

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**Keywords:** Cement industry; Energy performance; Environmental performance; Integrated indicator

## 1. Introduction

Cement industry is one of the most important primary industries in the world. The cement demand is increased due to the needs of constructing new infrastructures as well as the needs of repairing and renovating the existing foundations to support the growths of population and economics. The total global cement production volume in 2016 is approximately 4174 million tons. It is 24.96% increased comparing to the total production in 2010 [1]. In cement production process, the raw material (e.g. limestone, shale and clay) is prepared, dried, ground, mixed

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and heated in cement kiln up to 1200 °C–1450 °C to produce an intermediate product called clinker. Clinker is then used as the main ingredient for cement. It is ground and mixed with other additives (e.g. limestone and gypsum) to produce either ordinary portland cement (OPC) or mixed cement. During the process, large amount of fossil fuels (e.g. lignite, sub-bituminous, bituminous, petroleum coke, diesel and bunker oil) and alternative fuels (e.g. agricultural waste, municipal waste and industrial waste) are combusted to provide heat for the cement kilns, dryers and preheat devices. Besides, a lot of electricity is consumed especially in cement kilns and grinding machines. Hence, to produce the large volume of cement, the enormous amount of energy is consumed. From the statistical data [1], the world average thermal energy consumption rate in 2010–2016 is in the range of 3498–3581 MJ/tonClinker while the electricity consumption is in the range of 101–107 kWh/tonCement. This means the thermal energy and the electricity consumption in year 2016, in case of average clinker: cement ratio is 1.2, could be as much as 12.46 million TJ/year and 446,651 GWh/year.

Besides the issues of energy consumption and fossil fuel depletion, the environmental impact issues especially climate change is also a main concern for the cement industry [2]. The greenhouse gas can be originated from both direct and indirect emission sources. The major direct emission sources are the calcination process (to decompose  $\text{CaCO}_3$  and  $\text{MgCO}_3$  containing in raw material to  $\text{CaO}$  and  $\text{MgO}$  which is required as the main composition for clinker) and the fuel combustion. For the indirect emission, the most significant source is the electricity consumption. Normally, the calcination process is accounted for 50%–60% of the overall greenhouse gas emitted while the fuel combustion and electricity consumption are accounted for 40%–50% and 5%–10%, respectively [1,3]. With the increase of cement production,  $\text{CO}_2$  can be emitted more than 3 billion ton annually [4]. Since the cement industry has an important role in economic, energy and environmental systems of many countries including Thailand, to achieve the sustainable development goal, it is necessary to develop the indicator that can be applied in national level, industrial level and company level. This indicator should not only reflect the energy performance. It should also reflect the environmental performance as well as related to the economic point of view. Besides, it is also necessary to set the benchmarking and the target of the performance of the cement industry. Then the company can be used as the reference for nation's sustainable development. In this study, several indicators (i.e. productivity-to-energy ratio, gross output-to-energy ratio, productivity-to-environmental impact ratio, gross output-to-environmental impact ratio and energy-environmental performance index) are introduced. The statistical data of cement industry during 2010–2016 are monitored and used to analyze the sector-level performance under the present situation. The data and the results are then used to forecast the performance in 2025.

## 2. Conceptual framework and methodology

The objective of this paper is to study the energy-environmental performance of cement industry in Thailand at current situation of energy consumption and greenhouse gas emission and to forecast the performance in 2025.

Firstly, the cement-sectorial statistical data (e.g. actual volume produced, production capacity, gross output in monetary value, thermal energy consumption by fuel type and electricity consumption) during 2010–2016 are collected. Then, the total thermal energy consumption (TEC) in TJ, the electricity consumption (ELC) in TJ, the gross output (GOV) in million THB and actual volume produced in million ton in each year (t) will be used to calculate the productivity-to-energy ratio (PER) and the gross output-to-energy ratio (GER) from the following equations.

$$PER_t = \left[ \frac{\text{Volume produced}_t}{TEC_t + ELC_t} \right] \quad (1)$$

$$GER_t = \left[ \frac{GOV_t}{TEC_t + ELC_t} \right] \quad (2)$$

Beside the energy performance, the environmental performance is also considered in this study. It is evaluated based on the greenhouse gas emission both from direct and indirect emission sources. Main direct emission sources include the calcination process, the combustion of total organic carbon (TOC) contained in raw material and the fuel combustion. The indirect emission source is the electricity consumption. In case of calcination process and TOC combustion, the greenhouse gas emissions are calculated from clinker and cement volume produced, clinker to cement ratio, raw material to clinker ratio,  $\text{MgO}$  and  $\text{CaO}$  content in clinker and the molecular weight of each related substance. The greenhouse gas from calcination can be calculated from

$$GHG_{cal,t} = \text{Cement Volume}_t \times E_{cal,t} \quad (3)$$

and

$$E_{cal,t} = f_{cem}^{clink} f_{clink}^{CaO} \frac{MW^{CO_2}}{MW^{CaO}} + f_{cem}^{clink} f_{clink}^{MgO} \frac{MW^{CO_2}}{MW^{MgO}} \quad (4)$$

where  $f_{cem}^{clink}$  is the clinker to cement ratio,  $f_{clink}^{CaO}$  is the fraction of CaO in Clinker,  $f_{clink}^{MgO}$  is the fraction of MgO in Clinker,  $MW^{CO_2}$  is the molecular weight of CO<sub>2</sub>,  $MW^{CaO}$  the molecular weight of CaO and  $MW^{MgO}$  is the molecular weight of MgO.

The greenhouse gas from TOC combustion can be calculated from

$$GHG_{TOC,t} = Cement\ Volume_t \times E_{TOC,t} \quad (5)$$

and

$$E_{cal,t} = f_{cem}^{clink} f_{clink}^{RM} \times f_{RM}^{TOC} \times \frac{MW^{CO_2}}{MW^C} \quad (6)$$

where  $f_{RM}^{TOC}$  is the fraction of TOC in raw material and  $MW^C$  is the molecular weight of carbon. The default TOC content in raw material referred from CO<sub>2</sub> and energy accounting and reporting standard for cement industry [5] is 2 kg per ton raw meal (corresponding to 0.2%)

Therefore, the greenhouse gas emissions that come from the raw material consumption ( $GHG_{RM}$ ) can be calculated from

$$GHG_{RM,t} = GHG_{cal,t} + GHG_{TOC,t} \quad (7)$$

In case of fuel combustion, the emission ( $GHG_{TEC}$ ) is calculated from fuel consumption ( $FC$ ), heating value of each fuel ( $HV$ ) and emission factors ( $E$ ). The fuel consumption and heating value referred from the Thai's energy data while the emission factor for each fuel type ( $i$ ) is referred from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories [6].

$$GHG_{TEC,t} = FC_{i,t} \times HV_i \times \left[ (E_{CO_2,i} \times GWP_{CO_2}) + (E_{CH_4,i} \times GWP_{CH_4}) + (E_{N_2O,i} \times GWP_{N_2O}) \right] \quad (8)$$

where  $GWP$  is global warming potential of each greenhouse gas referred from the 4th IPCC assessment report.

In case of electricity consumption, the emission ( $GHG_{ELC}$ ) is calculated from the electricity consumption quantities ( $EC$ ) and the emission factors ( $E_{elec}$ ). The emission factor is referred from Thai specific emission factors for greenhouse gas inventories in corporate level [7].

$$GHG_{ELC,t} = EC_t \times E_{elec} \quad (9)$$

Then, the annual productivity-to-environmental impact ratio ( $PEIR$ ) and the annual gross output-to-environmental impact ratio ( $GEIR$ ) are calculated from

$$PEIR_t = \left[ \frac{\text{Volume produced}_t}{GHG_{RM,t} + GHG_{TEC,t} + GHG_{ELC,t}} \right] \quad (10)$$

$$GEIR_t = \left[ \frac{GOV_t}{GHG_{RM,t} + GHG_{TEC,t} + GHG_{ELC,t}} \right] \quad (11)$$

where  $GHG_{RM}$  refers to summation of the greenhouse gas emission from calcination process of raw materials and the emission from combustion of TOC contained in raw materials in TonCO<sub>2</sub>-eq.  $GHG_{TEC}$  refers to the greenhouse gas emissions from thermal energy consumption in TonCO<sub>2</sub>-eq.  $GHG_{ELC}$  refers to the greenhouse gas emissions from electricity consumption in TonCO<sub>2</sub>-eq.

Then the performance indicator that can integrate the energy, environment and economic perspective is analyzed. The fossil fuel consumption, the electricity consumption and the greenhouse gas emission (both direct and indirect emission) are converted to the environmental impacts as fossil fuel depletion and global warming based on the concept of life cycle assessment (LCA). The impacts are evaluated and expressed in term of monetary value by using Japanese life cycle impact assessment method based on endpoint modeling (LIME method) which is developed by Research Center for Life Cycle Assessment, National Institute of Advanced Industrial Science and Technology.

This value is adjusted by the annual inflation rate, purchasing power parities and GDP growth rate. The impact costs are then used to calculate energy-environment performance index (*EEPI*) by following equations

$$EEPI_t = \left[ \frac{GGOV_t}{GOV_t} \right] \tag{12}$$

$$GGOV_t = GOV_t - FRD_t - GW_t \tag{13}$$

where *GOV* refers to gross output in unit of THB, *FRD* refers to fossil fuel resource depletion impact in unit of THB and *GW* refers to global warming depletion impact in unit of THB.

### 3. Results and discussions

#### 3.1. Current situation and baseline performance

From the statistical data obtained from NESDB (Office of the National Economic and Social Development Council), OIE (Office of Industrial Economics), TCMA (Thai Cement Manufacturers Association) and DEDE (Department of Alternative Energy Development and Efficiency), the volume produced, the gross output value and the energy consumption of cement sector during 2010–2016 are collected. The gross output-to-energy ratio and the productivity-to-energy ratio are evaluated. The results are shown in [Table 1](#). It shows that, during 2010 to 2013, the volume of cement produced is steadily increased with the average growth rate of 7% due to the rapid growth of Thai economy. There are a lot of investments in infrastructure. But, during 2014–2016, the volume is quite stable and slowly dropped down. Since, the energy consumption varies in line with the volume of cement produced. It could be seen that the energy consumption is also increased during 2010–2013 and is decreased during 2014–2016. When considering the energy performance in term of the productivity-to-energy ratio or PER, the result shows that the energy performance of cement sector is gradually increased. Since PER is the ratio of productivity output to in energy input, it means that less energy is consumed to produce a given amount of cement product. On the contrary, the gross output value-to-energy ratio is reduced after 2014. It is due to the decrease of cement price. The average price of cement in 2016 is lower than the price in 2014 as much as 8.8%. The average GER and PER during 2010–2016 are 0.321 THB/MJ and 0.284 kg/MJ, respectively. As shown in [Fig. 1](#), it can be seen that about 92% of energy supplied to cement sector still comes from fossil fuels. It is down from 95% in 2010 and virtually unchanged since 2014 due to the higher price of biomass.

**Table 1.** Volume produced, gross output value, energy consumption, gross output-to-energy ratio and productivity-to-energy ratio of cement sector during 2010–2016.

Year	Volume produced Million ton	Gross output value Million THB	Energy consumption kTOE	PER <sub>t</sub> kg/MJ	GER <sub>t</sub> THB/MJ
2010	38.33	45,842	3,170	0.273	0.323
2011	38.67	47,124	3,271	0.267	0.326
2012	43.10	48,916	3,352	0.291	0.330
2013	45.45	51,129	3,615	0.284	0.320
2014	44.68	51,015	3,546	0.285	0.325
2015	44.06	47,541	3,556	0.280	0.302
2016	44.68	46,431	3,330	0.303	0.315
			Average	0.284	0.321

In term of the environmental performance, the greenhouse gas emission is estimated. The gross output-to-environmental impact ratio and the productivity-to-environmental impact ratio are evaluated. The results are shown in [Table 2](#) and [Fig. 2](#). It shows that the greenhouse gas emission is still varied in line with the cement production. The most significant emission source is calcination process and TOC combustion. It is accounted for approximately 61% in year 2016. Similar to PER, the productivity-to-environmental impact ratio or PEIR of cement sector is gradually increased. It means that less greenhouse gas is emitted during the cement production. This results from three main reasons. First, more waste heat recovery systems are installed in the cement industries and are used to generate the electricity. Therefore, the consumption of purchased electricity is much reduced. The second reason is

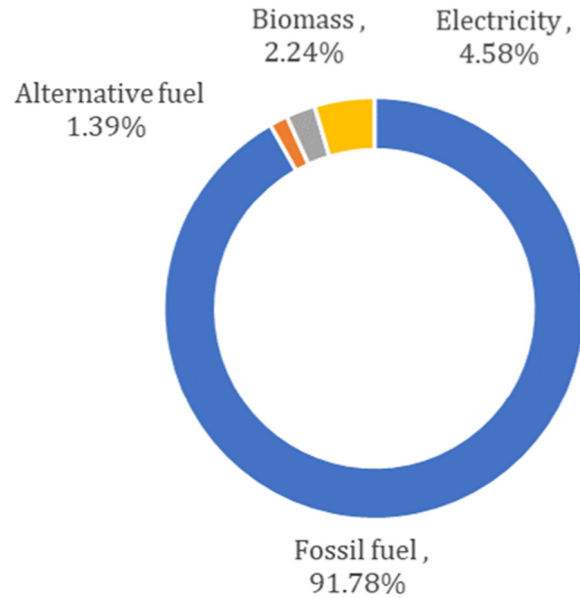


Fig. 1. Percentage of total energy supplied to cement sector by different energy source in 2016.

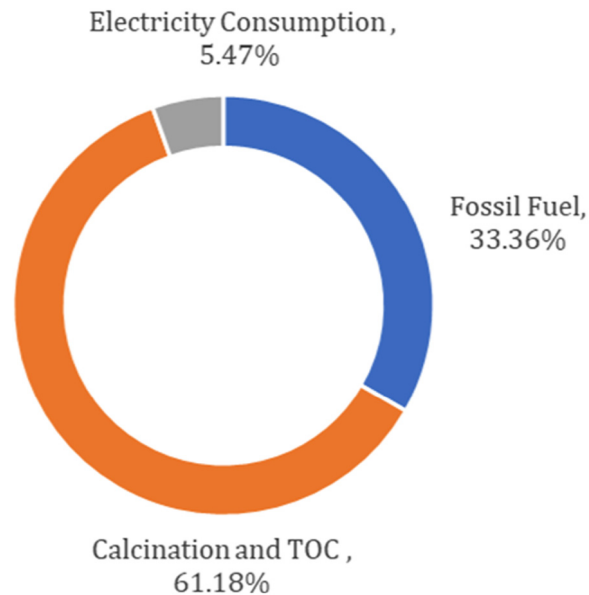


Fig. 2. Percentage of total emission by different emission source in 2016.

the utilization of biomass of which the emission factor is much lower than the fossil fuel. The third reason is that more alternative material (e.g. fly ash, bottom ash and other material which contains free CaO and MgO) are used as the substitute for clinker in cement mixing. When, the demand of clinker is decreased, the energy consumption in cement kiln is reduced. The emission from fuel combustion is decreased as well as the emission from calcination and TOC combustion.

Unlike PEIR, GEIR depends on the price change. Since the cement price during 2010–2016 is apparently changed and is not in line with either the volume produced or the amount of emission, therefore, GIER is quite fluctuated.

**Table 2.** Energy and environmental performances of cement sector during 2010–2016.

Year	Greenhouse gas emission	PEIR <sub>t</sub>	GEIR <sub>t</sub>	EEPI
	TgCO <sub>2</sub> -eq	kg/kgCO <sub>2</sub> -eq	THB /kgCO <sub>2</sub> -eq	
2010	36.08	1.271	1.062	0.69
2011	36.24	1.300	1.067	0.66
2012	38.89	1.258	1.108	0.68
2013	40.23	1.271	1.130	0.67
2014	43.02	1.186	1.039	0.69
2015	37.81	1.257	1.165	0.71
2016	36.90	1.258	1.211	0.74
	Average	1.256	1.111	0.70

The average PEIR and GEIR of cement sector during 2010–2016 is 1.256 kg/kgCO<sub>2</sub>-eq and 1.111 THB /kgCO<sub>2</sub>-eq, respectively.

At this point, to consider the energy performance and the environmental performance separately, PER and PEIR are recommended as the indicator for accounting the performance of cement sectors as they are free of price change.

However, to consider all perspectives of energy, environment and economic, the other indicator called energy-environment-economic performance index or *EEPI* is introduced. The consumptions and the emissions are the environmental impacts and expressed in term of monetary value. Then, the cost of impacts are used to calculate *EEPI*. The results are shown in [Table 2](#). Since the fossil fuel consumption, the electricity consumption and the greenhouse gas emission per unit of cement produced are annually decreased, the cost of environmental impact is also decreased. Although the price of cement is lower in the past two year but because the reduction of impact has more effect, therefore, the energy-environment-economic performance of cement sector becomes increased. It could be seen that the performance is increased from 0.69 in 2014 to 0.74 in 2016 (7% increase). Since all data required for the *EEPI* calculation are the basic data for most companies, it means that the company can estimate its performance at the company level as well. Therefore, *EEPI* could be one of an interesting alternative for using as the benchmarking indicator.

### 3.2. Performance target in 2025

In this part of the study, the data during 2010–2016 are used as the baseline for forecasting the clinker production, cement production, fuel consumption and electricity consumption in 2025 by using an econometric model with linear regression method. The model is expressed as a function of various factors including GDP growth rate, population growth rate, domestic demand growth rate, cement consumption per capita and production capacity. The waste heat recovery rate, the proportion between fossil fuel and alternative fuel (fossil-based and biomass-based) and the fraction of alternative material in cement in 2025 is assumed to be the same as in 2010–2016. The factors for baseline scenario are shown in [Table 3](#).

**Table 3.** Factors for forecasting baseline scenario.

Factors	Unit	Value	Factors	Unit	Value
GDP growth rate	%	3.8	Cement consumption per capita	Ton/capita	0.45
Population growth rate	%	−0.02	Maximum clinker production capacity	Million ton	52
Domestic demand growth rate	%	2.36	Maximum cement production capacity	Million ton	60

From these factors and assumptions, the energy consumption and the greenhouse gas emission in 2025 becomes 4223 ktoe and 52,271TgCO<sub>2</sub>-eq, respectively. *EEPI* of the baseline scenario is 0.73.

However, to support the target of energy conservation and greenhouse gas mitigation of the country, it is necessary to reduce the energy consumption in cement sector in year 2025 at least 280 ktoe per year and reduce the greenhouse gas emission at least 400,000 tonCO<sub>2</sub>-eq per year comparing to the baseline scenario. Thus, the waste heat recovery rate has to be up to 60% of the maximum capacity. The proportion between fossil fuel and alternative fuel has to be at least the same as in 2013 of which the proportion of alternative fuel (biomass-based fuel) is the highest.



The fraction of alternative material in cement should be at least 65% of maximum fraction allowed based on Thai industrial standard for cement product. It could be found that *EEPI* of the cement industry could be up to 0.75. Therefore, the recommended benchmarking for the company level performance is 0.73 and the target performance of the company level should be equal to 0.75

Although the variation of the amount of raw material consumed (e.g. limestone, shale and clay) is already considered during the evaluation of the performances in this research, however, the natural resource depletion impact caused from raw material consumption as well as the impacts caused from the fossil fuel consumed during quarrying and transportation process are not yet included. These impacts should be added in the future work to generate the benchmark that can reflect the performance of the cement sector throughout its supply chain.

#### 4. Conclusion

The cement industry has an important role in energy conservation and greenhouse gas mitigation in Thai's economy system. During 2010–2016, the energy and environmental performances based on the productivity (expressed in term of productivity-to-energy ratio: PER and productivity-to-environmental impact ratio: PEIR) are gradually increased. It means less energy is consumed and less greenhouse gas is emitted to produce a single unit of cement. However, the energy and environmental performances based on the value of cement produced (expressed in term of gross output-to-energy ratio: GER and gross output-to-environmental impact ratio: GEIR) are quite fluctuated due to the change of cement price in each year. Therefore, in case of considering the energy performance and environmental performance separately, the indicator based on physical output as PER and PEIR is more suitable. The result shows that, under the current situation, PER and PEIR of cement industry are 0.284 kg/MJ and 1.256 kg/kgCO<sub>2</sub>-eq, respectively. In case of considering the energy and environmental perspectives simultaneously, the energy-environmental performance index or EEPI is suggested. All factors are converted to the monetary value and are adjusted by the annual inflation rate, purchasing power parities and GDP growth rate. This integrated indicator could prevent the shifting from one impact to another and it could be evaluated for both industry-level and company-level. Therefore, it could be use as the benchmarking for the company. The average EEPI during 2010–2016 is 0.70. From the forecasting, the baseline-scenario EEPI in 2025 is 0.73. However, to support the target of energy conservation and greenhouse gas mitigation of the country, it is necessary to increase EEPI up to 0.75.

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