ENERGY CONSUMPTION AND CO_2 EMISSION CHANGES OF BUILDING MATERIAL INDUSTRIES IN 1996-2018: INPUT-OUTPUT ANALYSIS

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Abstract

In the industrial sector, burning of fossil fuels results in the emission of greenhouse gases, which is considered as one of the major causes of climate change and global warming. The purpose of this study is to determine trends in energy consumption and CO_2 emission from the building materials industry (cement, glass, products from baked clay) in the period of 1996 to 2018. Input-output tables of Vietnam was used to calculate total energy consumption and CO_2 emission for each sector. The results show that in 2018, total energy consumption was about 18223.612ktoe, total CO_2 emission was about 73917.608kt$CO_{2\text{-e}}$. The cement industry contributes 70% of both total energy consumption and CO_2 emission in 2018. In order to decrease the CO_2 emission from cement industry in the future, several solutions such as co-processing of wastes in cement kiln, recovery of waste heat generation, and use of alternative materials are proposed.

Keywords: *Input-output table, Building materials, Greenhouse gases, Energy consumtion, CO_2 emission*

1. Introduction

The total of greenhouse gases (GHGs) emission in Vietnam is increasing rapidly in recent years. GHGs are known to be a major contributor to global warming and climate change. Ministry of Natural Resources and Environment had submitted three versions of national communication to the United Nations Framework Convention on Climate Change (UNFCCC), in the year of 2003, 2010, 2019 respectirely [1,2]. The published results show that from 1994 to 2014, total GHGs emission of Vietnam increased rapidly from 103.83 to 283.97 million tons of CO_2 equivalent ($CO_{2\text{-e}}$). The energy sector increased fastest from 25.64 to 171.62 million tons of $CO_{2\text{-e}}$ (Gt $CO_{2\text{-e}}$). Total GHGs emission from the energy sector are forecast to be 648Gt $CO_{2\text{-e}}$ by 2030. GHGs emission from the energy sector are mainly due to fuel combustion almost fossil fuels [2-4].

Since the late 1970s, many researchers have focused on extending the Leontief IO framework to account for inter-industry energy flows and GHGs emission [5-8]. A so-called Input-output Energy (IOE) typically determines the total energy consumed in delivering the product to the final demand, both as the energy consumed by an industry's production process and as the energy embodied in that industry's inputs. The net energy analysis in the energy production system is defined as the subtraction of the energy to create and sustain a process from the energy produced by the process. Junxia Peng et al. (2012) have studied the use of the IO table to calculate CO_2 emission for ceramic tile manufacturing units in Foshan City, China [9]. Xueliu Xu et al. (2017) calculated CO_2 emission from the Chinese trade industries [10]. Megha Shukla et al. (2007) have published studies on CO_2 emission using IOE model in India [11]. In Vietnam, energy consumption and air emission of 50 economic sectors have been evaluated for the years of renovation using IOE model [12].

In Vietnam, the main building material products include cement, glass, and products from baked clay such as tile, ceramic and brick. The production of these products consumes energy and raw materials, resulting in large emission of GHGs. The common approach for estimating emission from the industries is to use emission factors and data collected through direct surveys [3, 4]. In fact, The United States Agency for International Development (USAID) cooperated with the Vietnam Institute for Building Materials to estimate GHGs emission of building material industries from 2012 to 2015 following IPCC guidelines [3]. The results show that total emission in 2015 were 58.267Gt $CO_{2\text{-e}}$, the average annual growth rate of emission is about 2.8%. From 2016 to 2018, Hai et al. studied the GHGs'inventory of some building material sectors including glass, ceramic and tile [4].

Many studies have focused on calculating greenhouse gas emissions for a single year [3-4, 9-11]. Besides, the energy consumption shares among economic sectors of Vietnam was not determined, so it cannot be identified as a key energy consuming sector. This study focuses on analyzing and evaluating both energy consumption and greenhouse gas emissions over the time series from 1996 to 2018 to show changing trends. As results, an overview of energy consumption demand and potential greenhouse gas emissions from the building materials industry in the past will be given, as well as the forecasts for the future can also be easily make.

2. Materials and Methodology

2.1. Brief of IO model

In IO work, a fundamental assumption which also is called as the inter-industry flows from *i* to *j* depend entirely on the gross output of sector *j*. It means if sector *j* represents vacuum cleaners, it is assumed that if there is an increase in the sales of vacuum cleaners, there will be a corresponding increase in the sales of electric motors that are used in vacuum cleaners. The basis of IO table is illustrated in Table 1. In this table,

Table 1. Input–output table of inter-industry flows.

		Purchasing sector					
		1	2	…	*j*	…	*N*
Selling	1	Z_{11}	Z_{12}	…	Z_{1j}	…	Z_{1n}
	2	Z_{21}	Z_{22}		Z_{2j}		Z_{2n}
	⋮	⋮	⋮		⋮		⋮
	n	Z_{n1}	Z_{n2}	…	Z_{nj}	…	Z_{nn}

From this concept, a ratio of input to output called *a technical coefficient (A_{ij})* is formulated. The technical coefficient denoted A_{ij} can be made using a Z_{ij}, the observed monetary value of the flow from input the i^{th} to the j^{th} sector, and x_j, the gross output of *j*.

$$A_{ij} = \frac{Z_{ij}}{x_j} \quad (1)$$

Matrix for A_{ij} and vectors for x_i, f_j are defined as the follows:

$$A = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & \cdots & A_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nn} \end{bmatrix} x = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} f = \begin{bmatrix} f_1 \\ f_2 \\ \vdots \\ f_n \end{bmatrix} \quad (2)$$

There is an explicit definition of a linear relationship between input and output. The system of equations for *n* sectors in matrix form is constructed as follows:

$$(I - A)x = f \quad (3)$$

An IO table includes a part of competitive imports, therefore, to reflect domestic energy requirements, the vector of imports, *m*, is subtracted from the final demand, *f*.

$$y = f - m \quad (4)$$

The corresponding vector of gross output is derived from:

$$x = Z + y \quad (5)$$

IO tables are usually drawn up in monetary unit, but for energy analyses, the use of physical or energy unit is common. Since the middle of 1970s, the energy-based IO model in *hybrid unit* has been developed by Herendeen [6]. The basic idea is to substitute energy rows expressed in monetary unit with energy unit in the IO table. In this study, the hybrid unit system will be described as follows: first, constructing a diagonal matrix called *unit conversion matrix*, U, which includes ones and non-one elements in the diagonal. The non-one elements, U_{ee}, are factors for converting the monetary unit into energy unit and denote the location of energy sectors. Then, obtaining the corresponding Z^*, x^*, y^* in hybrid unit by multiplying *U* by *Z*, *x*, *y*, respectively.

$$Z^* = UZ \quad x^* = Ux \quad y^* = Uy \quad (6)$$

Hence, in these, energy rows are expressed in energy unit and non-energy rows are expressed in monetary unit. The corresponding technical coefficient matrix can be also obtained by

$$A^* = Z^*(\hat{x}^*)^{-1} = UZ\hat{x}^{-1}U^{-1} = UAU^{-1} \quad (7)$$

Where ^ denotes a diagonalized matrix.

Then, if we denote a vector of direct energy intensity by α^*, the amount of energy consumed by productive system can be expressed as $\alpha^* x^*$.

2.2. Estimation of energy consumption and CO_2 emission

In this study, the IO tables of Vietnam which was published by the General Statistics Office - Ministry of Industry and Trade of Vietnam has been used as main data source [13]. There are two other main data sources. One is The Statistical Yearbooks of Vietnam from 1996 to 2018 [14]. The other is IPCC Guidelines for National Greenhouse Gas Inventory, which obtain net calorific values and carbon emission factors of each type of energy [15]. Other data such as production data, raw material, fuel price,… is from national reports, annual industry reports of The Ministry of Construction, and survey data.

The IO tables of Vietnam in 1996, 2000, 2007, 2012 and 2018 were aggregated into 28 sectors and converted into hybrid-unit tables in which energy sectors are presented in energy units. Three sectors including Coal *(N4)*, Gasoline, oil and lubricants *(N10)* and Gas *(N18)* are considered as energy sources. Electricity is secondary energy therefore this sector is not considered as an energy provider but energy producer in order to avoid double counting.

In the calculation process, the price index for each categoryisestimated based on sectorial GDP data and output values in the Yearbooks. Price of coal is yearly averaged according to General Statistical Office's data; price of gasoline, oil and gas are yearly averaged according to Petrolimex's data. Kilotons of oil equivalent *(ktoe)* is used as a unit of energy consumption. The heat value in proportion to each fuel is determined from valuable sources [14,15].

Direct energy consumed in sector *i* is determined as the following:

$$EC_i = \sum_n^{j=1} E_{i,j} \quad (8)$$

Where:

EC_i: Total energy consumption of sector *i*, *TJ*

$E_{i,j}$: Energy consumption of sector *i* by fuel *j*, *TJ*

The energy conversion factors are taken according to the regulations of the Ministry of Industry and Trade. This factors are calculated differently for each industry.Then, CO_2 emission of sector *i* is determined as the following:

$$CEC_i = \sum_n^{j=1} E_{i,j} * EF_{n,j} * GWP_n \quad (9)$$

Where:

CEC_i: CO_2 emission of sector *i*, *kg* CO_{2-e}

$E_{i,j}$: Energy consumption of sector *i* by fuel *j*, *TJ*

$EF_{n,j}$: GHGs emission factor *n* for fuel type *j*, *kg/TJ*

GWP_n: the global warming potential factor.The GHGs emission is converted to CO_{2-e} by ussing the Global Warming Potential (GWP) values of GHGs for 100 years.

3. Results and discusions

3.1. Energy consumption and trends

Using the energy-based IO model, the energy consumption of 28 economic sectors of Vietnam (1996-2018) are revealed in Figureure 1 and Figureure 2. Total energy consumption for the whole economy (including final demand) in 1996, 2000, 2007, 2012 and 2018 was 7,282*ktoe*; 12,116*ktoe*; 26,000*ktoe*; 36,964*ktoe* and 62,708*ktoe*, respectively. Building materials *(N12)* always was the largest coal consumer. This sector occupied the highest ratios, 25% of total energy consumption in 2018, respectively. As the trend shown, coal use decreased while gasoline and oil use increase during the last twenty-five years.

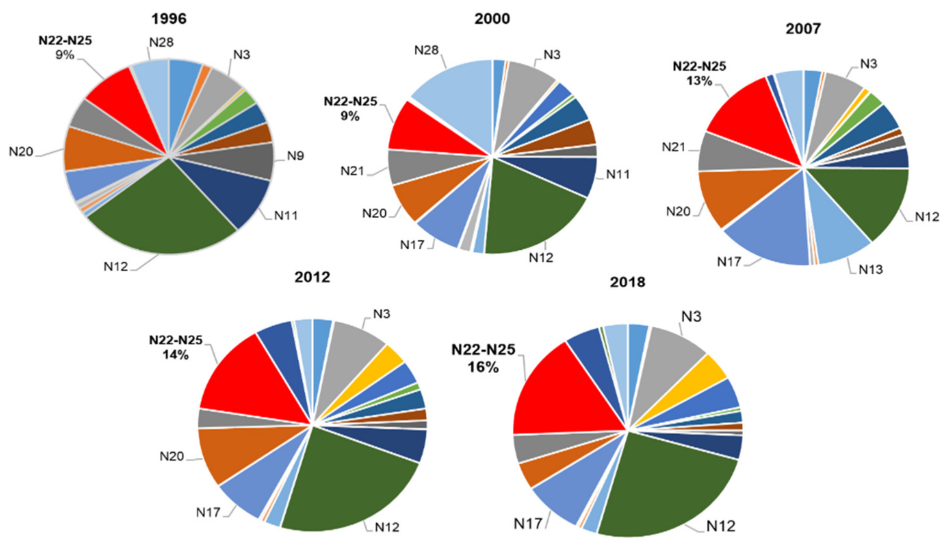


Figure 1. The energy consumption shares among economic sectors of Vietnam (1996-2018).

Notes: N1: Agriculture and its services; N2: Forestry and its services; N3: Fishery and aquaculture; N4: Coal; N5: Crude oil and natural gas or LPG; N6: Extractive; N7: Food processing; N8: Fashion manufacture; N9: Paper and its service; N10: Gasoline, oil and lubricants; N11: Basic chemicals; N12: Building materials; N13: Metal production; N14: Electronic, electric and other equipment production; N15: Transport means production; N16: Medical equipment; N17: Electrical production and delivery; N18: Gas; N19: Water; N20: Construction; N21: Trading, repairing services of automobiles, motorcycles and motors; N22: Railway transport service; N23: Road transport service; N24: Waterway transport service; N25: Aviation transport service; N26: Telecommunications and tourism services; N27: Insurance service; N28: Other services.

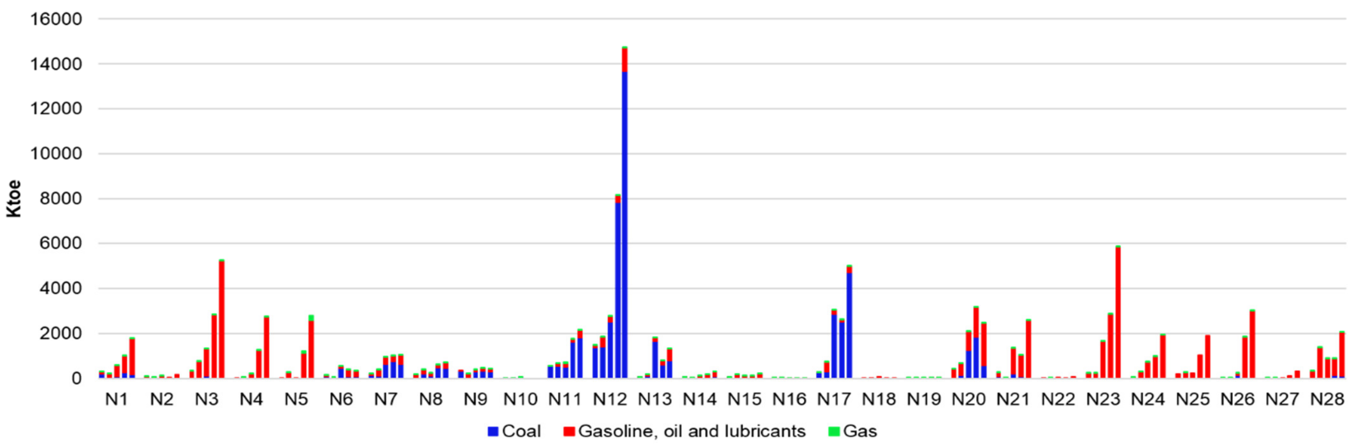


Figure 2. Energy consumption of 28 economic sectors of Vietnam in 1996, 2000, 2007, 2012, 2018.

Note: In each sector, the left, the middles and the right column indicate the value of 1996, 2000, 2007, 2012 and 2018, respectively.

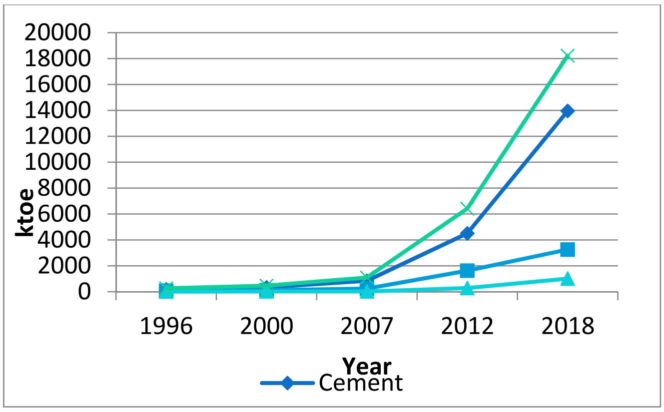
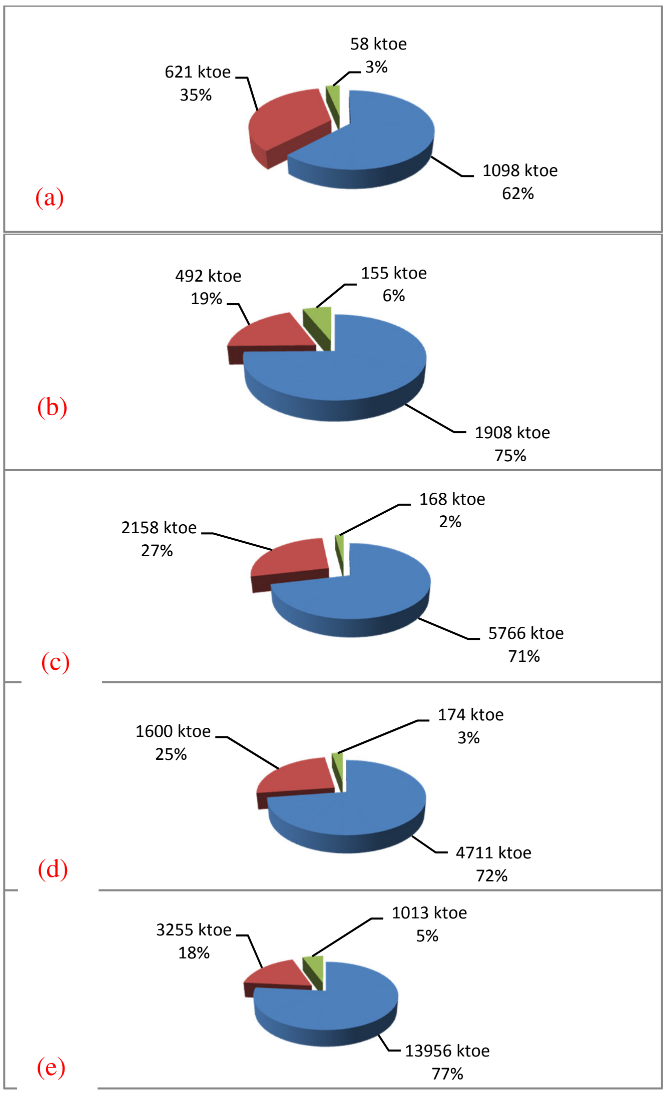


Figure 3. Energy consumption trends.



Notes: (a) 1996, (b) 2000, (c) 2007, (d) 2012, (e) 2018

Cement Products from baked clay Glass

Figure 4. The energy consumption shares of consumption by sectors.

As in many developing countries, energy use in Vietnam has been driving by industrialization, urbanization, motorization and individual enrichment. During the past twenty-five years, many manufacturers in industrialized nations have brought energy-intensive industries to Vietnam, due to lower labor cost, less stringent environmental regulation and lower overhead, lower transportation costs. Most of technology used in the Vietnamese industry is imported from industrialized countries. While this is expected to fall energy demand, the use of obsolete and inefficient technology imported from industrialized countries leads to the unreasonable increase of energy demand.

Total energy consumption of building materials industry was 1767.068; 2554.084 and 8902.147ktoe in 1996, 2000, and 2007, respectively. In 2012, this sector consumed 6415.21ktoe and increment to 18223.61ktoe in 2018. The result of estimated energy consumption was shown in Figure. 3.

Since 1996, the demand for total energy consumption has increased nearly 10 times after 12 years. From 2007 to 2018, there is a strong increase in energy consumption. The period of 2012-2018 showed that the peak of the increase in total energy consumption about 2.8 times, of which the level of increasing energy consumption of cement, products from baked clay, and glass industry, respectively 3.1; 2.0 and 3.5 times. The increase in energy consumption represents a strong increase in demand for production to meet market demand.

The energy consumption shares of consumption by each industry were showed in Figure. 4. The result shows that Cement industry consumes the most energy, accounting for 62-77% of the total energy consumption. Besides, this number is increasing rapidly over the years due to the rapid development of the cement industry. According to the announcement of the world cement association, as of December 2019, Vietnam was the fifth-largest cement-producing country. Production of baked clay products consumes about one-fifth of total energy and is on a downward trend. Glass production shows an increase in energy consumption, but only accounts for 2-6% of the total energy consumption.

3.2. GHGs emission and trends

The GHGs emitted for each sector in the years calculated include CO_2, CH_4, N_2O then converted to CO_2 equivalent (Figure. 5). The total GHG emission of building material industries in 2018 were 73917.608kt $CO_{2\text{-}e}$, an increase of 2.9 times compared to 2012, and an increase of nearly 10 times compared to 1996. In 2012, there is a sharp growth in the total CO_2 emission of all sectors and continues to keep the growth until 2018, with no signs of reduction. Increased GHGs emission are directly related to increased energy consumption and the type of fuel used to provide energy.

Cement continues to be the biggest contributor to GHGs emission accounting average more than 73% of CO_2 emitted, peak in 2018 contributing over 78.8%. The trend of increasing emission of the cement industry is very clear and strong, this adversely affects the total emission because a small emission increase in the cement industry can lead to a big increase in total emission.

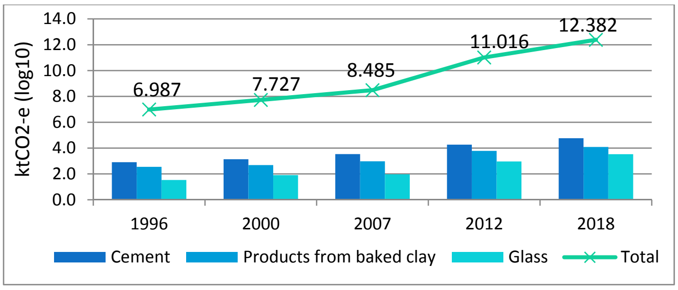


Figure 5. CO_2 emission trends.

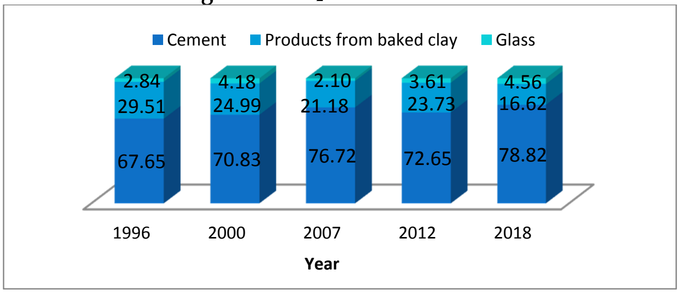


Figure 6. The CO_2 emission shares of consumption by sectors.

The second-largest emission is the manufacturing industry of baked clay products with a total CO_2 emission in 2018 of 12.3kt $CO_{2\text{-}e}$, accounting for 23.2% of the total emission on average.The glass industry is the lowest GHGs emission, accounting for 3.5% of the total emission on average. The emission growth ratio of glass industry is stable from 1996 to 2018. In this period, there was no major change in production technology also the number of plants. Also, this is the only industry that does not use coal fuel as the main energy source. These reasons explain the trend of stable GHGs emission in this sector.

3.3. Solutions to help reduce energy consumption and GHGs emission in the cement industry

As the results of this study, the cement industry accounts for over 70% of energy consumption as well as GHGs emission. Therefore, it is imperative to solutions to reduce energy consumption and emission for the cement industry. Some key solutions are researched and summarized in this study as follows:

1) Co-processing of solid wastes/ hazardous wastes in cement kiln

Co-processingof waste in cement kilns is considered one of the most effective solutions to reduce energy consumption. According to the results collected at the Hon Chong cement plant-Kien Giang and the Thanh Cong III cement plant -Hai Duong, burning waste can replace 30-40% of coal demand for clinker kilns. This directly reduces 30-40% of coal use. The difficulty of applying this technology in Vietnam is high investment cost as well as the control pollution issues that may arise from the co-processing. This makes many cement plants not ready to apply. However, this is the expected solution in the future.

2) Recovery of waste heat generation

Waste heat recovery is also one of the effective solutions for the cement industry. Excess heat from clinker kiln with a high temperature of 500-900ºC is very suitable for a small capacity power system. Many cement plants in Vietnam have applied this solution and showed the ability to replace 20-30% of electricity demand [16,17]. Almost power plants in Vietnam are coal-fired thermal power plants. Therefore, reducing electric consumption means reducingcoal consumption and CO_2 emissionas well.

3) Use alternative materials

Using various types of waste-based products in the manufacturing process as alternative fuelsis an indirect measure to reduce energy demand for the cement industry. Through the use of waste-based products such as fly ash, bottom ash will reduce energy consumption for the cement grinding process and save electricity. Besides, the use of waste as an alternative fuel means needless natural minerals. This leads to reduced energy consumption for the mining process and indirectly reduces energy demand and GHGs emission.

4) Carbon capture and storage

One of the solutions that are being focused on by researchers is the capture and storage of CO_2 emitted in the cement industry. CO_2 could be captured, stored, and used as a raw material for other industries. With the application of this technology, the cement industry will be one step closer to the zero-carbon industry [18,19]. This solution is still in the research phase and is expected to be implemented in the future.

4. Conclutions

The IO table has been used effectively in determining energy consumption and CO_2 emission for building materials industry from 1996 to 2018. Total energy consumption has increased rapidly over the past 20 years, especially in the past 6 years (from 2012 to 2018). Along with increasing energy demand, the building materials industry also emits more GHGs into the environment. Total emission are directly proportional to total energy consumption but with a smaller intensity due to science and technology with measures to reduce and treat emission. The cement industry is the biggest in both energy consumers and CO_2 emission. The second-largest is the products from baked clay industry. The glass industry plays the smallest role. Measures to reduce energy consumption and reduce GHGs emission for the cement industry have been introduced and promise to help bring the cement industry to zero-carbon.

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