# A Study about Energy Demand and Consumption in the Cement Industrial Sector in the Brazilian State of Minas Gerais

Fernando M. Costa, Antonella L. Costa* and Ricardo B. Pinheiro

*Universidade Federal de Minas Gerais, Escola de Engenharia - Departamento de Engenharia Nuclear, Av. Antônio Carlos, 6627 Campus UFMG, CEP 31270-901 Belo Horizonte, MG, Brazil*

**Abstract:** The Portland cement is one of the most important building materials and highly employed by mankind. Its high participation in human development, as a basic material for any type of construction, characterizes the cement industry as one of the main sectors for the economic and social development. It represents approximately 3% of energy consumption in Minas Gerais (MG), a Brazilian State. To perform this study, it was collected a set of energy consumption parameters and process data, besides economic indicators. Minas Gerais houses the majority of cement plants installed in Brazil. Each stage of production was identified and quantified as related to the energy consumption. Initially, the projection of the final consumption of the main energy sources was developed with the average growth method. Then, the future energy demand was calculated using the ENPEP-BALANCE model, for a 20-year analysis period. Results showed that the final energy demand of this sector in the State of Minas Gerais could vary from 1,475 to 2,642 thousand toe, which represents about 34% more or less 15% of the registered demand of the base year. Last, CO2 emissions were projected for the considered scenarios.

**Keywords:** Cement industry, Energy planning, Energy demand, ENPEP.

## 1. INTRODUCTION

The energy sector comprises the whole set of activities involved in production, transformation, storage, transportation, distribution and marketing. This sector is part of a broader set, which includes physical infrastructure and service delivery framework. All these activities are inserted in a context of local availability (perpetual or finite resources), geopolitics (import/export), socio-environmental (social pressures) and technological (viability of resource extraction) impacts. Another point to consider is the large necessity of capital investment in this sector. Some developing nations even spend more than 30 % of their total budget on energy projects [1].

Therefore, it is necessary to plan the activities involved in the entire energy chain. Energy planning aims to promote a rational use of the various forms of energy and optimize their supplies, in a context of multiple dimensions that result in impacts on economic, social and environmental policies. Each of these dimensions, which cover basically all human activity, present different objectives, which warns that energy planning should be widely discussed and analysed by all agents involved in this activity.

Specifically, about the cement sector, due to the great competition among the economic groups of the national and international market, new strategies have been emerging in this sector. Thus, energy demand assessment is vital for the strategic planning of this sector and the economic, commercial and processes performance improvement. In addition, this information will support the development of policies and technologies focusing on increasing the efficient use of energy in the manufacturing plant and/or the economic group. On this regard, in this paper proposes a time projection of the energy demand of the cement sector in the Brazilian State of Minas Gerais (MG), where it represents approximately 3% of energy consumption in such State.

This study used the Energy and Power Evaluation Program (ENPEP-BALANCE) to perform the projections. It is a nonlinear equilibrium model that matches the demand for energy with available resources and technologies [2]. The following important characteristics determined the choice of this model:

a) ENPEP is used in more than 50 countries;

b) ENPEP is free;

c) ENPEP model is user friendly, requiring approximately one week of training for basic applications or two weeks for advanced applications.

In the ENPEP-BALANCE module, a grid is constructed using different nodes and links representing various components of the energy system. In this process, a net is designed to track the flow of energy from primary sources to the useful energy demand (end use). It shall contain information

*Address correspondence to this author at the Universidade Federal de Minas Gerais, Escola de Engenharia - Departamento de Engenharia Nuclear, Av. Antônio Carlos, 6627 Campus UFMG, CEP 31270-901 Belo Horizonte, MG, Brazil; Tel: 55 31 34096662;
E-mail: antonella@nuclear.ufmg.br

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on the production, conversion, transportation, distribution and use of energy in the activities of the system under study, as well as the flow of energy and fuels belonging to such activities. Nodes represent processes, such as an industrial boiler, while links represent the flow of energy between blocks. The energy network is developed according to the flow of energy between different types of nodes, where each node is associated with specific equations that relate prices and energy flows in the incoming and outgoing connections.

### 1.1. Cement Industry

Portland cement is one of the most important building materials and highly employed by mankind. Its practical definition is: "hydraulic binder resulting from the homogeneous blend of Portland clinker, gypsum and finely ground normalized additions."

Brazil is among the largest cement producers in the world. There are 100 plants currently installed, owned by 24 national and foreign economic groups, whose capacity reaches about 100 million tons per year. The majority of these plantsare installed in Minas Gerais, 16 in total [3].

Cement is basically produced from limestone extraction, its processing chemical and thermal operations and further mixing with materials such as gypsum and additives. The cement production can be sorted in following stages, considering the magnitude of the energy consumption:

- Preparation of raw materials;
- Preparation and crushing of the raw material;
- Homogenization and burning (clinker production);
- Cement milling and finishing.

The ABCP (Brazilian Association of Portland Cement) [3] defines 8 basic types of Portland cement, according to the type and quantity (% mass) of additives, and to which purpose it will be used. The production process of each kind of cement presents different specific consumption of heat and electric energy, but for the purpose of this study it will be considered in this work only the manufacture of Common Portland Cement (CPC).

The production process considered in this work will be the dry process, through rotary kilns with cyclone preheaters, because they are the most adopted today and characterized by the most efficient use of energy.

The performance of the cement industrial sector is a good economic indicator of a country. As cement consumption is directly linked to per capita income, it implies future changes in the development of a region or country and depends on several factors such as the demand generated by construction, raw material availability or reserves, market access and the economic conditions of each region.

Despite the significant participation, Brazil still has a lower national per capita consumption of cement in comparison with those from several developed and developing countries. Figure **1** shows the difference between the Brazilian per capita consumption of cement per capita and the world per capita consumption. It also presents the direct relation between the global economic milestones in Brazil and the consumption of cement.

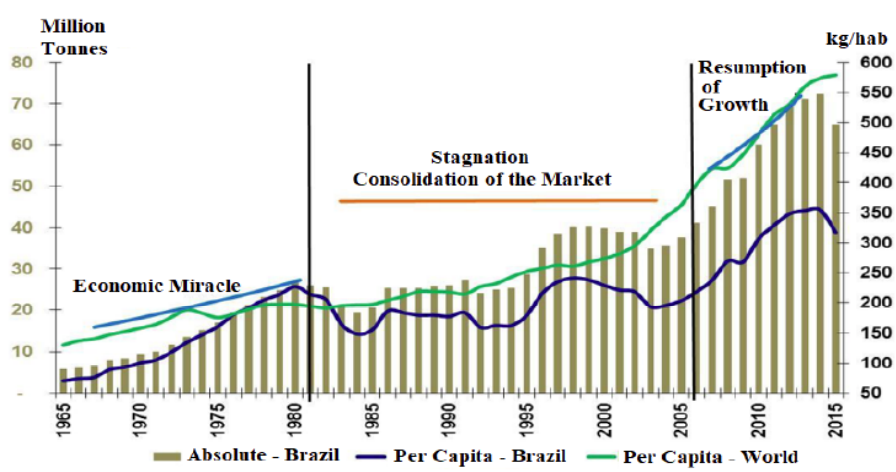


**Figure 1:** Apparent consumption of cement in Brazil. Adapted from [5].

In addition to a low per capita consumption, one can also mention that Brazil has a high housing deficit, around 6.3 million households, and in Minas Gerais this deficit is around 545 thousand [4]. The country also lacks investments in infrastructure, such as ports, airports, highways, electricity and sanitation. Thus, this sector has still much to expand in Brazil. Cement is a labor-intensive industry. About 25,000 workers are directly employed; the State of Minas Gerais is the largest producer in the country and, consequently, the largest job creator in the cement sector [5].

### 1.2. Environmental Impacts

The generation of waste and gaseous effluents is one of the main problems of the cement industry. The reduction of energy-related production costs, the necessary observance of principles contained in the National Policy of Solids Wastes and the Environmental Crimes Law, led the industry to coprocessing industrial waste in rotary kilns, by use of waste in replacing conventional fuels. In some cases, part of the waste is processed for the sole purpose of replacing the inorganic components of raw meal, alumina, silica or iron oxide, and not counted for the thermal energy requirements.

There is a high polluting potential in the cement industry, depending on the fuel used, mainly by the emission of atmospheric pollutants composed of particulate matter, nitrogen oxides and sulphur, volatile organic compounds, halogenated acids, heavy metals, dioxins, furans and others [6]. The operating conditions of the process, the chemical and mineralogical composition of the raw materials and the fuels used determine the physical, chemical and toxicological characteristics of the emissions of this industrial segment.

Coprocessing has been occurring in some cement plants with the use of various types of waste and in significant proportions of fuel substitution. This large variety of processed wastes depends on the region and the seasonality. It is possible to highlight some residues such as sugarcane bagasse, rice husks, coconut husks, wood residues, charcoal, firewood, tars, petcoke, coke mill, carbonaceous tailings, peat, tires and others. Attention will be given to petcoke due to its significant consumption in recent years in this sector.

World cement production is estimated to account for 5% of global $CO_2$ emissions [7]. One ton of cement releases approximately 0.8 tons of $CO_2$ into the atmosphere.

$CO_2$ emissions per ton of cement produced depend on the energy resources involved in the production cement.

In this industrial segment, carbon dioxide represents more than 99% of the total greenhouse gas emission. Other gases, such as nitrogen oxides, methane and carbon monoxide, have a small share. Among the energy sources used by this industry, natural gas generates less $CO_2$, with an emission factor of around 15.3 $tCO_2/TJ$, although it has the highest non-$CO_2$ emission coefficient, especially NOX [8].

## 2. THE CEMENT INDUSTRY IN MINAS GERAIS

As an energy-intensive sector, due to the concentration of many manufacturing units and because it leads domestic production, the cement sector in Minas Gerais has relevant energy consumption (about 3% of total consumption) (Figure **2**).

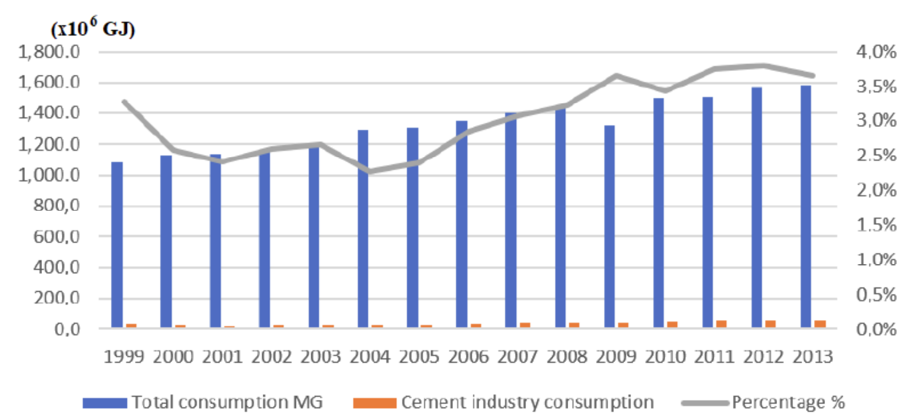


**Figure 2:** Total energy consumption in MG and the energy consumption in the cement sector in MG. Adapted from [9].

In a cement plant, it is possible consider two major uses of energy: heat production (clinker process) and drive motors.

To produce one tonne of clinker it would be necessary to supply 1,737 MJ of heat [10]. This value is calculated considering the theoretical chemical reactions involved in the process. This specific energy consumption value represents a reference value for comparing the efficiency of an actual process.

In the dry production process with preheater, the specific heat consumption is between 3,350 and 3,600 MJ/t of clinker, which means an efficiency of approximately 51% compared to the theoretical value [10]. In the Table **1** it is presented the use of energy in the clinker production.

**Table 1: Energy Consumption Involved in the Clinker Process [10]**

| Process | MJ/t of Clinker | % |
|---|---|---|
| Heat for reaction | 1,737 | 51.88 |
| Gas and dusty heat | 711 | 21.24 |
| Cooling air | 565 | 16.88 |
| Losses in the walls | 335 | 10.01 |
| **Total** | **3,348** | **100.00** |

In addition to the heat demand, the cement plants have a high consumption of electricity. Electricity is used to drive motors, used in lifting and transporting machines, mills, feeders, fans, electrostatic precipitators, lighting and other auxiliary services. The grinding processes are those that present a greater consumption of electric energy. As shown in Table **2**, these represent more than 70% of the total electricity consumption in a cement plant.

**Table 2: Total of Average Electrical Energy Consumption in the Cement Plant [10]**

| Stages of Consumption | % |
|---|---|
| Preparation of Raw Materials | 3 |
| Preparation and Crushing of the Raw | 32 |
| Homogenization and | 21 |
| Cement Milling and Finishing | 41 |
| General and Auxiliary Services | 2 |
| Lighting | 1 |
| **Total** | **100** |

Due to the high energy consumption in the cement manufacturing process, especially as heat, the use of low-cost fuels has always been sought throughout history. This high variety in the use of different fuels is presented in the Table **3**, which presents historical variations of the energy inputs used by the sector in Minas Gerais between the years 2005 to 2013. The large participation of petcoke, representing 54% of the energy inputs used in the sector during the analysed period is notable.

Table **4** presents the specific energy consumption by cement production over the study period. Thus, it means that in Minas Gerais on average it takes about 3,783 MJ of energy to produce one tonne of cement. This value is close to that shown in Table **1**.

Considering the average participation percentage of the main fuels used in the state of Minas Gerais, presented in Table **3**, and the calculated specific consumption (Table **4**) it is possible to estimate the consumption of each fuel by tonne of cement produced. This relation is presented in Table **5**.

**Table 3: Use of Fuels in the Cement Industry in MINAS Gerais ($10^6$ GJ) [9]**

| Energy resource | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | Avg | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Coal | 0.46 | 1.05 | 3.01 | 1.47 | 2.72 | 0.63 | 0.71 | 0.33 | 0.38 | 1.20 | 2.53 |
| Fuel oil | 0.50 | 0.80 | 0.67 | 0.50 | 0.46 | 0.46 | 0.21 | 0.17 | 0.13 | 0.43 | 0.92 |
| Electricity | 4.19 | 4.86 | 5.74 | 6.74 | 6.57 | 7.16 | 7.62 | 7.87 | 8.25 | 6.55 | 13.90 |
| Charcoal | 7.75 | 9.09 | 7.41 | 10.26 | 8.25 | 8.88 | 11.26 | 14.03 | 13.61 | 10.06 | 21.32 |
| Petcoke | 15.53 | 19.76 | 23.49 | 24.58 | 26.96 | 30.90 | 29.01 | 28.14 | 32.74 | 25.68 | 54.44 |
| Others | 3.01 | 3.10 | 2.68 | 2.85 | 3.48 | 3.48 | 2.85 | 4.94 | 2.85 | 3.25 | 6.88 |
| **Total** | **31.44** | **38.64** | **43.00** | **46.39** | **48.44** | **51.50** | **51.67** | **55.48** | **57.95** | **47.17** | **100** |

**Table 4: Specific Fuel Consumption by Cement Production [3, 9]**

| | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | Avg |
|---|---|---|---|---|---|---|---|---|---|---|
| Clinker Production ($10^3$ t) | 8,981 | 9,679 | 10,800 | 12,021 | 12,330 | 13,454 | 14,478 | 15,642 | 14,868 | 12,473 |
| Energy Consumption ($10^3$ GJ) | 31,443 | 38,644 | 42,998 | 46,390 | 48,441 | 51,498 | 51,665 | 55,475 | 57,945 | 47,185 |
| Specific consumption (GJ/t) | 3.50 | 3.99 | 3.98 | 3.85 | 3.92 | 3.82 | 3.56 | 3.54 | 3.89 | 3.78 |

**Table 5: Fuel Consumption by Tonne of Cement Produced**

| Energy resource | MJ/t |
|---|---|
| Coal | 95.89 |
| Fuel oil | 34.70 |
| Electricity | 525.73 |
| Charcoal | 806.70 |
| Petcoke | 2,059.66 |
| Others | 260.44 |
| **Total** | **3,783.12** |

**Table 6: Cement Production - Consumption of Electricity by Cement Production**

| Stages of Consumption | MJ/t |
|---|---|
| Preparation of Raw Materials | 15.77 |
| Preparation and Crushing of the Raw | 168.24 |
| Homogenization and Burning | 110.40 |
| Cement Milling and Finishing | 215.55 |
| General and Auxiliary Services | 10.51 |
| Lighting | 5.26 |
| **Total** | **525.73** |

Considering the percentages of the electric energy consumption by the main processes presented in Table **2** and the specific consumption of the electric energy by cement production presented in Table **5**, it is possible to calculate the electric energy consumption for each stage of the process as it is presented in Table **6**.

The main equipment responsible for the energy conversion along the various stages of the cement manufacturing process with their respective conversion efficiencies are presented in Table **7**.

## 3. ENERGY DEMAND FORECASTING OF CEMENT INDUSTRY IN MG – STUDIED SCENARIOS

Since energy planning aims to ensure the continuity of energy supply in a given future, the analysis of energy demand becomes the focal point of the study. Energy demand is a result variable, influenced of several factors some of which are beyond the control of the agents that determine their availability (suppliers or consumers). These factors, economic, social, technological, among others, present a relationship of independence between them, thus forming a large network of mutual influences where the point of

**Table 7: Process Efficiencies [10, 11]**

| Stages of Consumption | Equipment | Efficiency (n) | Conversion |
|---|---|---|---|
| Preparation of Raw Materials | Crusher | 5% | MWh/t of crushed limestone |
| Preparation and Crushing of the Raw | Ball Mill (A) | 8% | MWh/t of ground limestone |
| Homogenization and Burning | Electric motor | 98% | Electric energy in mechanical energy |
| | Kiln | 51% | MJ/t of clinker |
| Cement milling and finishing | Ball Mill (B) | 10% | MWh/t of ground clinker |

convergence occurs in the variable energy demand. Therefore, for the elaboration of possible scenarios, future situations must be raised that, according to the related uncertainties, will directly impact the energy demand.

Two main variables are identified that influence the entire network of causalities of energy demand in this industrial sector: economic development and technological development.

Thus, the construction of possible scenarios of the energy demand of the cement industrial sector in Minas Gerais will be based on these variables presented in Figure **3**, where the central axes will be Economic Development and Technological Development.

For the Economic Development axis, in addition to the economic performance variable, was consider the projection of the population of the State of Minas Gerais. The union of these variables results in the indicator annual per capita consumption of cement (kg/inhabitant/year).

Following an increasing economic development, it is expected that Brazilian per capita consumption of cement will also grow, reaching in the long term the level observed in the developed countries, namely is, it will increase from 413 to 596 kg/inhabitant/year. As this indicator is a synthesis of two important variables, it will be used to build the possible scenarios of the Economic Development axis.

For the Technological Development axis, it was considered the increase of the energy efficiency in the production processes. As already quoted, the International Energy Agency estimates that by 2050, there will be a great technical potential overall of energy savings - from 28 to 33% [12]. It was considered that the energy efficiency gain will occur in the thermal processes of clinker production, *i.e.* in the kiln.

It was also considered that the State will maintain its percentage share in national production, of 23%. Thus, four future scenarios were established (Figure **4**). They were considered: 1) Technological Advancement & Economic Advancement, TA & EA, 2) Technological Advancement & Economic Stagnation, TA & ES, 3) Technological Stagnation & Economic Advancement, TS & EA, 4) Technological Stagnation & Economic Stagnation, TS & ES.

Table **8** presents the numerical values of the variables to be considered for the elaboration of the four scenarios.

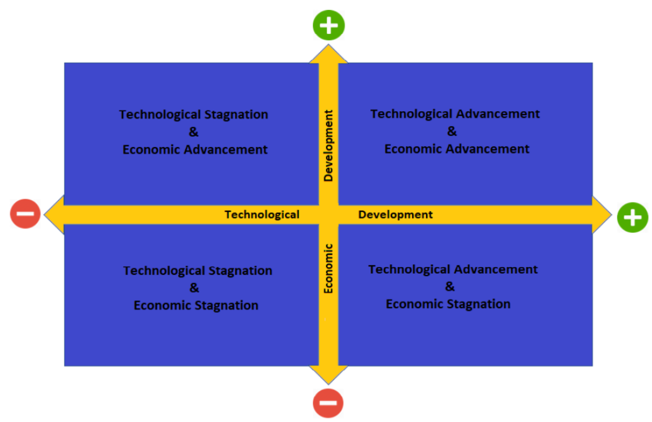


**Figure 4:** The four considered scenarios in this study.

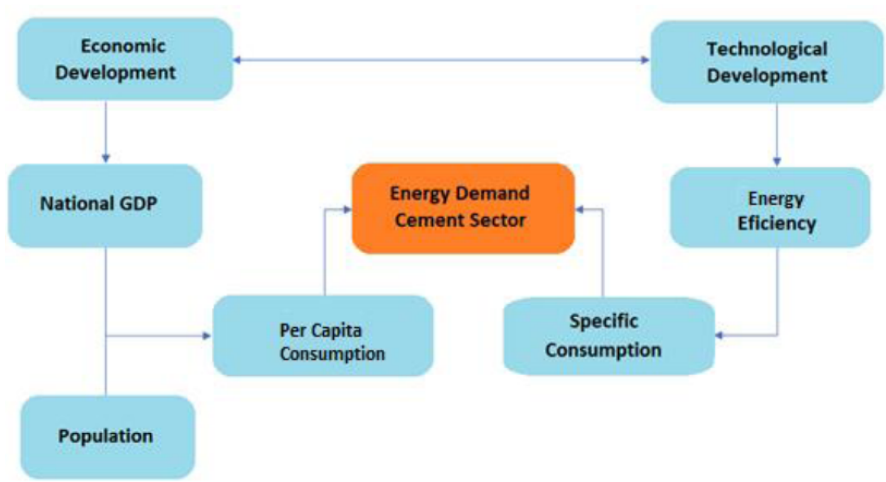


**Figure 3:** Summary of the Causality Network of energy demand in the industrial cement sector.

**Table 8: Scenarios Description**

| Scenarios | | | Characteristics | |
|---|---|---|---|---|
| **Case** | **Name** | **Description** | **Economic Development** | **Technological Development** |
| 1 | TA & EA | Technological Advancement & Economic Advancement | Increase of per capita consumption of cement reaching 596 kg/inhab/year in 2035 | 30% increase in energy efficiency (reduction of specific consumption) |
| 2 | TA & ES | Technological Advancement & Economic Stagnation | Maintenance of current per capita consumption (413 kg/inhab/year) | 30% increase in energy efficiency (reduction of specific consumption) |
| 3 | TS & EA | Technological Stagnation & Economic Advancement | Increase of per capita consumption of cement reaching 596 kg/inhab/year in 2035 | No increase in energy efficiency (maintenance of current specific consumption |
| 4 | TS & ES | Technological Stagnation & Economic Stagnation | Maintenance of current per capita consumption (413 kg/inhab/year) | No increase in energy efficiency (maintenance of current specific consumption |

## 4. RESULTS

Data input and calculation of the balance supply/demand balance for energy in ENPEP-BALANCE was carried out based on an energy network representative of the sector to be studied. The energy network was constructed using 20 nodes and interconnected by 19 links [13].

The results are presented at Figure **5**.

-ENPEP also calculates the useful energy demand, *i.e*. the energy used in the final process after the intermediate conversions, for each scenario (Figure **6**).

Correlating the information presented in the Figure **5** and **6**, the evolution of the energy efficiency of the cement industry in MG is calculated for the four

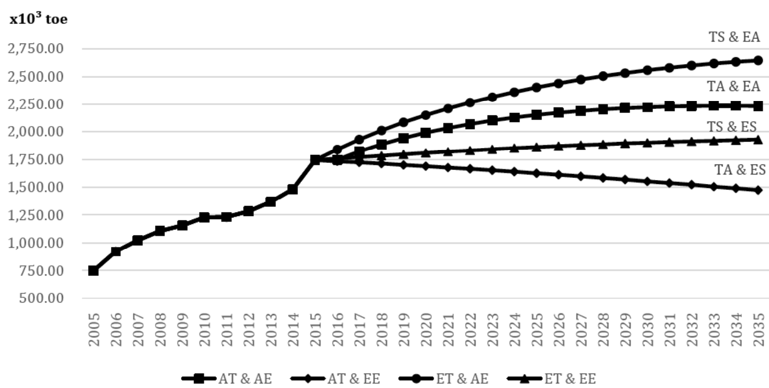


**Figure 5:** ENPEP result for the projection of the energy demand of the cement industrial sector in MG.

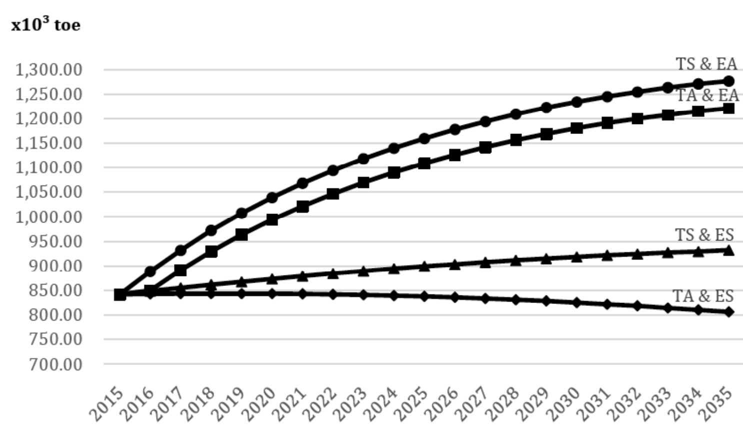


**Figure 6:** ENPEP result for the projection of the useful energy demand.

scenarios presented. In the base year, 2015, the energy efficiency of the process, calculated by the ratio between the useful energy demand and the total energy demand of the system, is equal to 48%. For scenarios where there was technological advance, TA & EA and TA & ES, energy efficiency was 55% in the year 2035. For the others, energy efficiency remained the same as the base year.

To validate the modeling developed in this work, it was performed a simulation based on the growth trends presented for each scenario in Figure **6**, which was compared to the real situation. This simulation was performed considering the period to consolidate the base year, that is, from 2005 to 2015. This result is presented in Figure **7**.

It was concluded that, from the results presented, the scenarios that more closely approached the situation occurred in the period presented, were those that considered the occurrence of an economic advance, namely TA & EA and TS & EA.

This fact validates the modeling developed in this work. There is proximity of the simulated values to reality, and also coherence of the scenarios that presented values close to the situation occurred in the country: average economic growth of approximately 3% per year during this period.

Regarding the technological performance of the sector, which would result in gains in energy efficiency, no reference was found in the literature about the sector.

### 4.1. Energy Demand for Each Scenario

#### *4.1.1. Scenario TA & EA*

In this scenario it was considered that there will be a technological advance, resulting in the increase of the energy efficiency of the productive process. A gain of 13.95% compared to the base year [13]. It was also considered that there will be progress in the economy of the country, resulting in an increase in per capita consumption of cement, from 413 kg per capita in the base year to 596 kg in the year 2035. This scenario is presented in Table **9**.

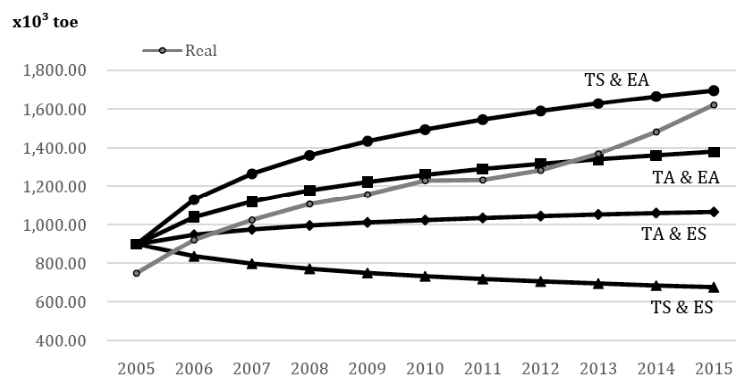


**Figure 7:** Simulation of the energy demand during the history considered for the construction of the base year.

**Table 9: Energy Demand by Source for Scenario TA & EA**

| Energy Resource | Energy Demand (x10³ toe) | | | | |
|---|---|---|---|---|---|
| | 2015 | 2020 | 2025 | 2030 | 2035 |
| Electricity | 244.42 | 288.51 | 321.91 | 342.60 | 354.30 |
| Petcoke | 977.69 | 1,110.42 | 1,193.93 | 1,226.09 | 1,224.99 |
| Charcoal | 366.63 | 416.40 | 447.72 | 459.78 | 459.37 |
| Natural Gas | 17.46 | 19.83 | 21.32 | 21.90 | 21.88 |
| Fuel oil | 26.19 | 29.75 | 31.98 | 32.84 | 32.81 |
| Coal | 26.19 | 29.75 | 31.98 | 32.84 | 32.81 |
| Others | 85.00 | 96.54 | 103.80 | 106.60 | 106.50 |
| TOTAL | 1,743.58 | 1,991.18 | 2,152.65 | 2,222.66 | 2,232.66 |

#### 4.1.2. Scenario TA & ES

In this scenario it was considered that there will be technological advance, following the same values presented by the TA & EA scenario, but there will be stagnation in the economy, thus maintaining the same per capita consumption of cement of the base year, that is, 413 kg per inhabitant over of the analysed horizon. This scenario is presented in Table **10**.

#### 4.1.3. Scenario TS & EA

In this scenario it was considered that there will be a technological stagnation, that is, there will be no improvement in the energy efficiency of the production process. However, there will be progress in the country's economy, resulting in an increase in the per capita consumption of cement following the same values presented by the TA & EA scenario, that is, per capita cement consumption will increase from 413 kg to 596 kg in the observed horizon. This scenario is the one that presents the higher demand of energy, as it is presented in Table **11**.

#### 4.1.4. Scenario TS & ES

In this scenario it was considered that there will be technological and economic stagnation. Without gaining in the energy efficiency of the production process and without increasing the per capita consumption of cement, thus, the increase in energy demand will only occur due to the fact that the Brazilian population increases over the analysed horizon [13]. Increasing the population, will increase the demand for cement generating consequently an increase of the production that will demand more energy by this sector. This scenario is presented in Table **12**.

### 4.2. Environmental Impacts

The generation of waste and gaseous effluents is one of the main problems of the cement industry. In this industrial segment, $CO_2$ contributes most to greenhouse gas emissions, representing more than 99% of the total. Other gases, such as nitrogen oxides, methane and carbon monoxide, have a marginal share.

**Table 10: Energy Demand by Source for Scenario TA & ES**

| Energy Resource | Energy Demand (x10³ toe) | | | | |
|---|---|---|---|---|---|
| | 2015 | 2020 | 2025 | 2030 | 2035 |
| Electricity | 244.42 | 244.84 | 243.24 | 239.61 | 234.15 |
| Petcoke | 977.69 | 942.40 | 901.79 | 857.17 | 809.24 |
| Charcoal | 366.63 | 353.39 | 338.17 | 321.44 | 303.46 |
| Natural Gas | 17.46 | 16.83 | 16.10 | 15.31 | 14.45 |
| Fuel oil | 26.19 | 25.24 | 24.16 | 22.96 | 21.68 |
| Coal | 26.19 | 25.24 | 24.16 | 22.96 | 21.68 |
| Others | 85.00 | 81.93 | 78.40 | 74.52 | 70.36 |
| **TOTAL** | **1,743.58** | **1,689.88** | **1,626.01** | **1,553.97** | **1,475.02** |

**Table 11: Energy Demand by Source for Scenario TS & EA**

| Energy Resource | Energy Demand (x10³ toe) | | | | |
|---|---|---|---|---|---|
| | 2015 | 2020 | 2025 | 2030 | 2035 |
| Electricity | 244.42 | 301.66 | 336.59 | 358.22 | 370.46 |
| Petcoke | 977.69 | 1.207.52 | 1.347.60 | 1.434.39 | 1.483.49 |
| Charcoal | 366.63 | 453.41 | 506.18 | 538.87 | 557.39 |
| Natural Gas | 17.46 | 22.50 | 25.37 | 27.16 | 28.20 |
| Fuel oil | 26.19 | 33.27 | 37.39 | 39.96 | 41.43 |
| Coal | 26.19 | 33.27 | 37.39 | 39.96 | 41.43 |
| Others | 85.00 | 100.14 | 110.40 | 116.70 | 120.13 |
| **TOTAL** | **1,743.58** | **2,151.78** | **2,400.92** | **2,555.26** | **2,642.52** |

**Table 12: Energy Demand by Source for Scenario TS & ES**

| Energy Resource | Energy Demand (x10³ toe) | | | | |
|---|---|---|---|---|---|
| | 2015 | 2020 | 2025 | 2030 | 2035 |
| Electricity | 244.42 | 253.52 | 260.96 | 266.64 | 270.47 |
| Petcoke | 977.69 | 1,014.10 | 1,043.85 | 1,066.49 | 1,082.58 |
| Charcoal | 366.63 | 380.28 | 391.44 | 399.93 | 405.96 |
| Natural Gas | 17.46 | 18.11 | 18.64 | 19.05 | 19.33 |
| Fuel oil | 26.19 | 27.17 | 27.96 | 28.57 | 29.00 |
| Coal | 26.19 | 27.17 | 27.96 | 28.57 | 29.00 |
| Others | 85.00 | 88.17 | 90.75 | 92.72 | 94.12 |
| **TOTAL** | **1,743.58** | **1,808.52** | **1,861.58** | **1,901.96** | **1,930.47** |

The ENPEP model is capable to predict the emission scenarios [14].

The $CO_2$ emission factor has been calculated for each source [13] (Table **13**), and was used to predict the emissions for the four studied scenarios.

**Table 13: $CO_2$ Emission Factor by Source for Cement Industry [13]**

| Energy Resource | x10³ kg $CO_2$/toe |
|---|---|
| Natural Gas | 1.75392 |
| Coal | 3.29073 |
| Firewood | - |
| Diesel Oil | 2.53575 |
| Fuel Oil | 2.59425 |
| Electricity | - |
| Charcoal | 3.29730 |
| Petcoke | 3.41954 |

From the values presented in Table **13** it is possible to calculate the $CO_2$ emission for each investigated scenario (Figure **8**).

From the information on cement production in MG and the projection of $CO_2$ emission, the specific emission of $CO_2$ was calculated for each scenario, as it is presented in Figure **9**.

In Figure **9**, it is notable that in scenarios where technological development is absent, the specific emission of $CO_2$ remained almost constant throughout the period. In the scenarios where there was technological advance, the specific emission reduced significantly, as it was expected, from 610 kg $CO_2$/ton cement to 456.22 kg $CO_2$/t cement, about 23% compared to the specific emission of the base year.

Considering that emissions from the calcination process are impossible to avoid, the focus should be

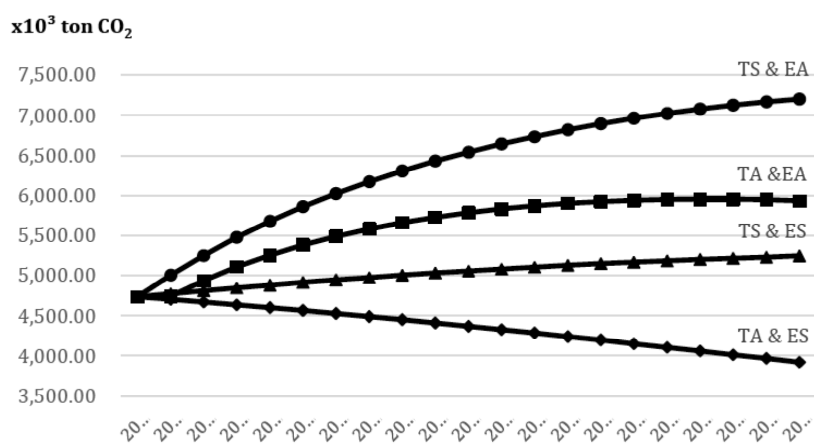


**Figure 8:** Projection of $CO_2$ emission for each scenario.

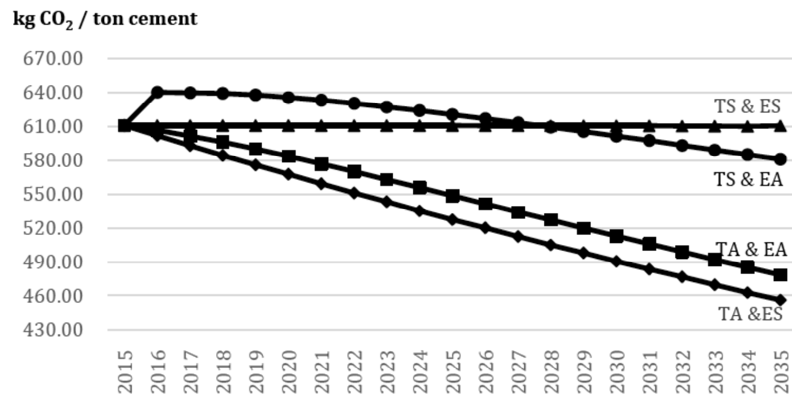


**Figure 9:** Projection of specific $CO_2$ emission for each scenario.

on the use of low carbon fuel and on increasing the energy efficiency in thermal processes.

As in the technological advancement scenarios, the efficiency gains of the thermal processes were considered, allowing cement production with a lower need of energy resources; the presented values are reasonable and achievable.

## CONCLUSION

The development of this work provided knowledge about the use of energy in the cement industry in the Brazilian State of Minas Gerais. This sector represents approximately 3% of the State energy consumption. Given that this sector is directly related to the development of the country's infrastructure and that there is much to be developed in Brazil, and that there is a large housing deficit, it is concluded that there will be expansion of this industrial sector, as can be verified through of the results of this work, and that the magnitude of this expansion depends greatly on factors related to the country's economic development and the technological development of this industry. In this sense, it could be noted that the expansion of the final energy demand of this sector in the State, could vary from 1,475 to 2,642 thousand toe, which represents about 34% above of the registered demand of the base year.

The expansion of the cement sector implies considerable impacts on the country's energy chain. In this sense, it is necessary detailed studies on the use of energy resources considering environmental aspects as well as economic impacts.

It should be noted that the technological advance, which result in an increase in the energy efficiency of the production process, is a factor of great relevance in this sector. As it was verified among the developed scenarios, the energy efficiency could vary from 48% to 55%, thus impacting the energy demand, and, more sensitively, the specific $CO_2$ emission, which would allow a variation between 456 and 610 kg $CO_2$/ton cement and would result in gross $CO_2$ emissions from 3,920 thousand ton $CO_2$ to 7,204 thousand ton $CO_2$.

In this work was carried out a Top-Down approach, due to the availability of sector information. In order to carry out more assertive forecasts, it is also proposed to carry out a Bottom-Up analysis, which would analyse the technical progress in a disaggregated way, that is, the technological innovations that produce gains of efficiency in the energy transformations in each productive stage. Thus, it will be possible to describe the limitations and barriers of the market, to improve the assertiveness of the model, and may even use other tools. After completing this analysis, make comparisons and promote the integration between Bottom-Up approaches (to be developed) with Top-Down (performed through this work), in order to allow the combination of approaches to improve demand projections power.

Another point of attention is the potential for increased energy efficiency in this industry. One of the technological solutions in this sense is the use of cogeneration in the process. Studies in this sense should be carried out, since it is a technology already consolidated in the market and practiced in some industrial segments such as steel mills.

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