Pertanika J. Sci. & Technol. 32 (S1): 55 - 68 (2024)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Energy Utilization and Production Assessment in a Cement Industry

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ABSTRACT

Cement industries are one of the fastest-growing economic sectors in developing nations like Ethiopia. It provides direct and indirect employment opportunities to a huge number of persons and contributes a major part to the nation's gross domestic product. Thus, the main objective of this study was to analyze the usage of power consumption and rate of production in the particular cement industry. For this purpose, a comprehensive study was conducted in the Messebo cement factory in northern Ethiopia, one of Ethiopia's key industries, which has unlimitedly contributed to Ethiopian economic development. It was achieved through primary and secondary data from the Messebo cement factory for the last seven years and compared with an actual and designed production rate and power consumption usage value. Besides money lost, profit and efficiency were analyzed based on the values of excess power used and production rate. From the results, the average usage of actual power and rated power has been observed to be 40.43 million kWh per year and 27.72 million kWh per year, respectively. In an average of seven years, the money lost due to excess power consumption and reduced production was estimated at roughly 4.4 million birr per year and 15 million birr per year, respectively.

Keywords: Cement factory, economic analysis, efficiency, power usage, production rate

ARTICLE INFO

Article history:
Received: 27 July 2023
Accepted: 17 October 2023
Published: 19 January 2024

DOI: https://doi.org/10.47836/pjst.32.S1.04

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ISSN: 0128-7680
e-ISSN: 2231-8526

INTRODUCTION

Ethiopia's cement industries have developed substantially in the past two decades. Moreover, challenges and barriers associated with the Ethiopian government's regulations and investment policy could erode these profits. A world highway reveals around 16.8 million tons of cement, an average of 10% growth in yearly consumption. Ethiopia is the topmost cement manufacturer in sub-Saharan Africa (Mulatu et al., 2018).

Energy is one of the important needs of human beings and is essential for the world's growth and will persist in developing to at least 1/3 by 2035 (Fedeler et al., 2021; Gebreslassie et al., 2022). Ethiopia is well placed to become the cement production hub of Africa because of the natural resources of surplus raw material for cement, lower labor cost, and accessibility of world market opportunity through agreement to avail free trading (Tesema & Worrell, 2015).

Messebo Cement Company is one of the biggest East African cement industries in the Tigray region in southern Ethiopia. Its products are used by many of the grand projects constructed by the government of Ethiopia and domestic and international contractors. In most housing development projects in the country, hydropower dams such as Tana Beles, Tis- Abay, Tekeze, Gilgel Gibe I, II & III, and heavy bridges were constructed with cement from Messebo. Even now, the supply and demand of the factory are not balanced; there has been very high demand, starting from the embellishment of the factory up to now (Messebo Cement Factory, 2015).

Cement production is performed through a series of activities, such as extraction of raw material, material preparation through ball mill, clinker burning, and cement milling and packing (Figure 1). In some cases, the raw material obtained from the resources is quite hard, and then it undergoes several stages for the dry cement process. Crushing is the first step, and the materials are broken into minute sizes that vary based on the requirements. Then, the pulverized powders are placed in kilns and dried by heating at a preferred high temperature. The dried powders are transferred to heavy ball mills and tube mills to make the finest powder.

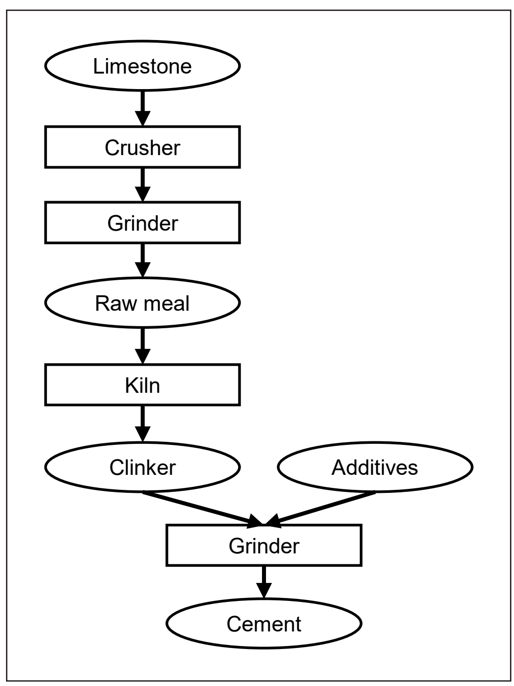


Figure 1. Process flow diagram for dry cement production

Finely dried materials are mixed in appropriate proportions mechanically or pneumatically (Gomes, 1990). The simplified production flow process for dry cement is shown in Figure 2.

Generally, the energy share compared to the production cost in the industries is in the range of 20 to 60% of operational costs (Galitsky & Worrell, 2008; Wang et al., 2009). It indicates that special attention is required to improve plant performance in the cement industry. As the various studies indicate, energy consumption varies with the processes involved in each part of the operation (Khajeh et al., 2014). The specific energy consumption for making powder is expected to range from 0.5 to 0.9 kWh/ton of materials (Bhatty, 2011).

Another important process is clinker production, where most of the energy is consumed, and over 90% of the total energy used by the industry is consumed. Clinker is prepared by pyro-processing in lengthy large rotary kilns consisting of up to eight meters tube diameter and laid at an angle of 3°C–4°C degrees that rotates two or three times per minute (World Business Council for Sustainable Development, 2014). The heat is required for the dry kilns at an average use of 4.7 MJ per ton of clinker. Typically, cement production is considered an energy-intensive stage process for both wet and dry, and consumption of energy accounts for 20%–40% of production cost (Hasanbeigi et al., 2012). Power consumption varies depending on the nature of the process involved. Power consumption for raw material preparation requires about 20–35 kWh /ton. Energy use for the operation of auxiliary machinery is expected to be roughly 10 kWh / ton of clinker. The process flow diagram for the cement production is shown in Figure 3.

Energy needs for grinding based on the requirement of surface area and energy required for heavy-duty ball mills may consume ranges from 32 to 37 kWh/ton (Schorcht et al., 2013; Seebach et al., 1996). Subject to high-temperature treatment, clinker is produced through a kiln, and its temperature is reduced drastically to change its properties (Gebreslassie et al., 2018). As reported by the European Cement Research Academy (ECRA), 2009, in a dry kiln cement industry, the usage of electricity is typically broken down as follows: 38% cement grinding, 24% raw material grinding, 22% clinker formation and grinding,

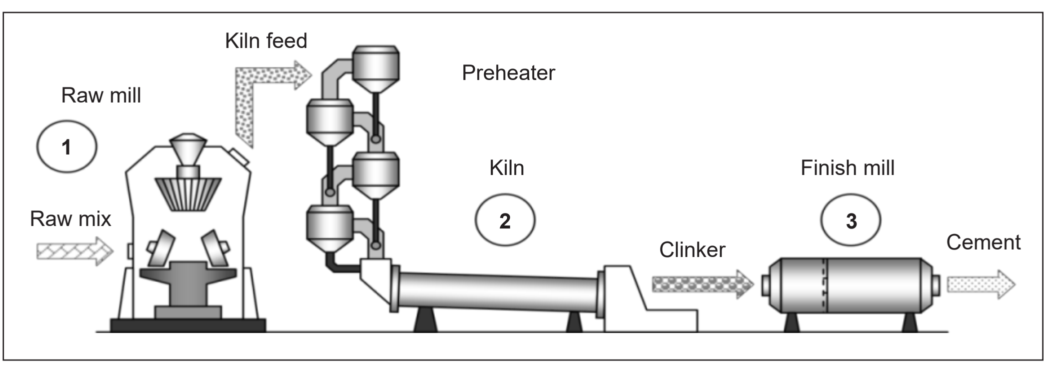


Figure 2. Simplified Schematic of the dry cement production process

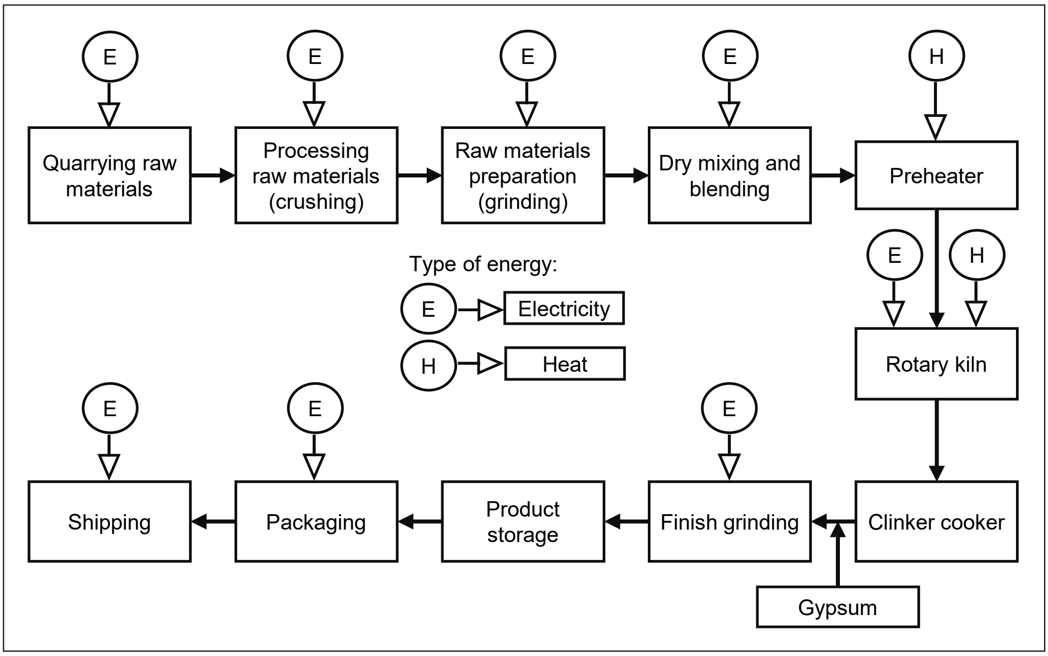


Figure 3. Process flow diagram for the cement production

6% homogenization of raw material, 5% raw material extraction and 5% for transportation and packaging (Schneider, 2017).

The objective of this article was to study the utilization of energy consumption and rate of production by considering various aspects. The energy bills and production rate were collected for the last seven consecutive years between 2012 and 2018. The expected scope of this study period would be valid up to 2024, associated with the production rate, specific energy consumption, raw material cost, and economic analysis.

MATERIALS AND METHODS

Cement production in the Messebo plant is processed through Lines 1 and 2. The performance study was carried out in Line 2, where two cement plants are operated, and each mill consists of a ball-type unit for crushing materials into minute fragments that vary in size. In this study, physical data collection, such as electricity bills, solid and liquid fuels, cement production rate, power consumption, and load factor, has been carried out. In addition to that, some of the physical measurements were taken from the machinery where major energy was consumed in the factory.

The physical measurements of actual production Pr_a (Ton/hr) for the 7 years from 2012 to 2018 were recorded from the register maintained in the company. Similarly, the actual specific power consumption, P_a (kWh/ton), for the 7 years from 2012 to 2018 was recorded from the register maintained in the log sheet.

Production and power consumption in the Messebo cement factory vary uncertain each year, and this has fluctuated year by year. However, as indicated in the technical specification, the designed rate of cement production (Pr_s) and rated energy consumption (P_s) of the plant were constant, recorded as 150 tons per hour and 33kWh per ton, respectively. The Messebo cement factory was designed to operate 8400 hours per year, and the designed production cost was found to be 356 birr per ton. Table 1 indicates the production rate and power consumption value for the Messebo plant in Line 2 (Messebo Cement Factory, 2019).

Table 1
Production rate and power consumption values of the cement plant in Line 2

Year	2012	2013	2014	2015	2016	2017	2018
Actual production Pr_a (Ton/hr)	135	77	67	98	99	120	104
Actual power consumption, P_a (kWh/ton)	46.49	52.58	57.78	52.31	45.27	41.48	47.24

Power Consumption

Generally, the specific energy consumption is expressed in kWh per ton of clinker. The excess power consumption by machinery of each process can be calculated by applying the Equations 1 and 2:

$$P_{e,i} = P_{a,i} - P_{s,i} \frac{kWh}{ton} \tag{1}$$

$$P_e = \sum_{i=1}^{n} P_{e,i} \quad \left(\frac{kWh}{ton}\right) \tag{2}$$

Excess power consumed during the operation of the cement mill for a specific year is calculated using two methods. One method is by multiplying an excess power per ton with an actual production rate per ton per year, and the second one is by subtracting actual power consumed per year and designing power consumption per year by applying the following relation:

$$P_{e,i} \ \frac{kWh}{year} = P_{e,i}\left(\frac{kWh}{year}\right) \times Pr_{a,i}\left(\frac{Ton}{year}\right) \quad = P_{a,i}\left(\frac{kWh}{year}\right) - P_{s,i}\left(\frac{kWh}{year}\right) \tag{3}$$

On the other hand, the actual power and designed power usage for specific years can be determined from Equations 4 and 5. A power quality analyzer measured the actual power consumption. Generally, power quality can be used to measure kW, kVAh, kWh, PF, kVARh, and Harmonics.

$$P_{a,i}\left(\frac{kWh}{year}\right) = P_{a,i}\left(\frac{kWh}{ton}\right) \times Pr_{a,i}\left(\frac{Ton}{year}\right) \tag{4}$$

$$P_{s,i}\left(\frac{kWh}{year}\right) = P_{s,i}\left(\frac{kWh}{ton}\right) \times Pr_{a,i}\left(\frac{Ton}{year}\right) \tag{5}$$

Production Rate

The production rate was synthesized and interpreted with data collected from the factory's monitor sheet. Generally, the actual production rate is different from the designed production rate of the cement mill. It is directly related to the plant efficiency of the cement factory. In order to analyze the total actual production of cement per ton per year, Equation 6 can be used (Madlool et al., 2013).

$$Pr_{a,i}\left(\frac{Ton}{year}\right) = Pr_{a,i}\left(\frac{Ton}{hr}\right) \times \left(\frac{hrs}{day}\right) \times \left(\frac{days}{year}\right) \tag{6}$$

The difference between the actual rate of production and the designed rate of production calculates the reduced production rate. The reduced production rate of cement for the specific year is determined by Equations 7 to 9 (Ayu et al., 2015):

$$Pr_{d,i} = Pr_{a,i} - Pr_{s,i}\left(\frac{Ton}{hr}\right) \tag{7}$$

$$Pr_d = \sum_{i=1}^{n} Pr_{d,i}\left(\frac{Ton}{hr}\right) \tag{8}$$

$$Pr_{d,i}\left(\frac{Ton}{year}\right) = Pr_{d,i}\left(\frac{Ton}{hr}\right) \times \left(\frac{hrs}{day}\right) \times \left(\frac{days}{year}\right) \tag{9}$$

Economic Analysis

Using excess power against a reduction in production rate can also be expressed in profit losses. The electricity tariff for high-voltage industries given by the Ethiopian electric power corporation is detailed in Table 2 (Messebo Cement Factory, 2019).

Table 2
Electricity tariff for high voltage industries

Particulars	Unit cost (birr/ kWh)
Equivalent flat rate	0.3904
Peak	0.4626
Off-peak	0.3544
Service charge	54.01

The total money loss of excess power consumption for the specific year can be determined by Equation 10:

$$P_{e,i}\left(\frac{birr}{year}\right) = \sum_{i=1}^{7}\left(\overbrace{P_{e,i}\left(\frac{kWh}{year}\right) \times \frac{birr}{kWh}}^{Excess\ electric\ power} + \overbrace{P_{e,i}\left(\frac{kWh}{year}\right) \times \frac{birr}{kWh}}^{for\ service\ charge}\right) \tag{10}$$

Money lost due to reduced production from the designed production rate is determined by multiplying the reduced production rate ($Pr_{d,i}$) and the expected profit per ton of the factory. Therefore, the total money lost due to the reduced production rate in all seven years is the sum lost each year, as expressed in Equation 11.

$$Pr_{d,i}\left(\frac{birr}{Year}\right) = \sum_{i=1}^{7}\left(Pr_{d,i}\left(\frac{Ton}{year}\right) \times Pr_{d,s}\left(\frac{birr}{Ton}\right)\right) \tag{11}$$

Total money loss from the cement plant in Line 2 due to improper electric power usage and an effective production rate in all seven years is calculated by adding some excess energy and reduced production. The cash profit of the factory varies from year to year, depending on the variation in production rate. As we have discussed, the designed production rate was about 150 tons per hour, which amounted to 1,260,000 tons per year. The designed value of anticipated production cost was to be 356 birr per ton. So, the expected and actual profit can be obtained from Equations 12 and 13.

$$\text{Expected profit per year (birr)} = \text{Pr}_{\text{s,i}}\left(\frac{\text{Ton}}{\text{year}}\right) \times \left(356\ \frac{\text{birr}}{\text{Ton}}\right) \tag{12}$$

$$\text{Actual profit per year (birr)} = \text{Pr}_{\text{a,i}}\left(\frac{\text{Ton}}{\text{year}}\right) \times \left(356\ \frac{\text{birr}}{\text{Ton}}\right) \tag{13}$$

Plant Efficiency

Cement plant efficiency (Equation 14) is determined by the ratio of standard power usage to the actual power usage of the plant (Worrell et al., 2013).

$$\eta_{P_i} = \frac{P_{s,i}}{P_{a,i}} \tag{14}$$

Also, production rate efficiency (Equation 15) is determined by the ratio of the actual production rate to the standard production rate.

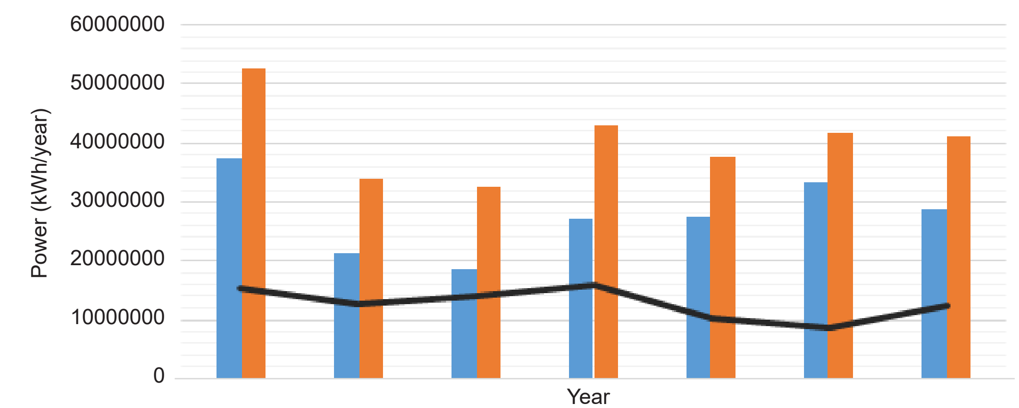
$$\eta_{Pr_i} = \frac{Pr_{a,i}}{Pr_{s,i}} \tag{15}$$

RESULTS AND DISCUSSION

The comprehensive study was conducted in the Messebo cement factory in the Tigray region in the northern part of Ethiopia, which is one of the key industries of Ethiopia. For this purpose, the last seven consecutive years between 2012 and 2018 were considered.

Power Consumption

Figure 4 shows the variation in power consumption usage for the last seven consecutive years between 2012 and 2018 and compares it with actual and designed power consumption. Generally, the efficient plant indicates that the actual power consumption should be approximately equal to the designed power consumption. Depending on the plant design system, power usage should be constant every year. It can be observed that the actual power usage was more than the rated power consumption for all seven consecutive years. From the figure, the average value of actual and rated power usage is 40.43 million kWh per year and 27.72 million kWh per year, respectively. It can also be observed that the horizontal line indicates an excess power lost during the cement plant operation, amounting to an average value of 12.71 million kWh per year.



	2012	2013	2014	2015	2016	2017	2018
Ps,i	37422000	21344400	18572400	27165600	27442800	33264000	28828800
Pa,i	52719660	34008744	32518584	43061592	37646532	41811840	41268864
Pe,i	15297660	12664344	13946184	15895992	10100664	8547840	12440064

Figure 4. Power consumption details of cement plant for seven consecutive years

Production Rate

The actual and designed production rates are plotted for the last seven consecutive years (Figure 5). The designed production rate is constant, almost 150 tons per hour, equivalent to 1.2 million tons per year. The percentage shown in the vertical axis indicates the quantity of cement production related to the expected value. In 2012, the reduced production rate was almost 10%, which seems to be 90% of the designed production rate achieved by the plant. However, the actual production rate has gradually been reduced for the other six consecutive years, as shown in the figure. In 2014, the reduced production rate was almost

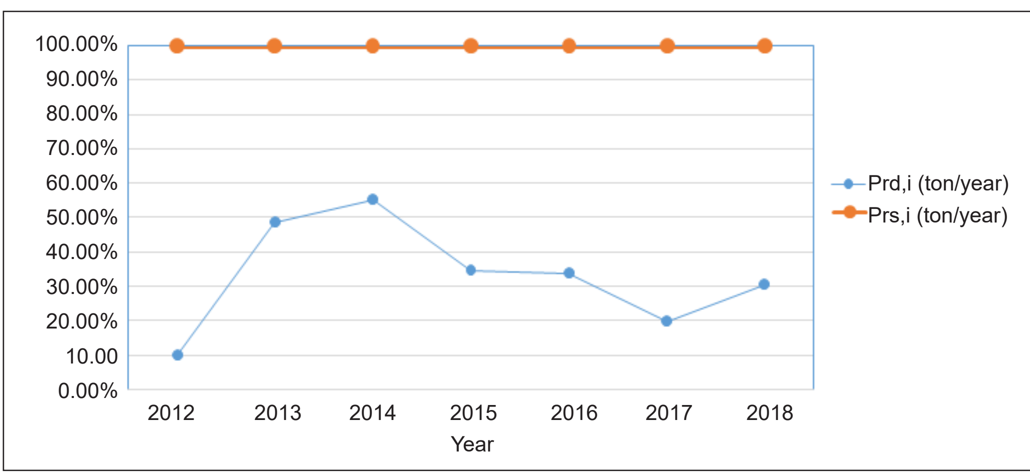


Figure 5. The production rate for seven consecutive years

56% of the designed rate, indicating that the actual production rate is 46% of the designed rate. It implies that the cement plant's performance was quite low, thereby increasing profit loss due to a lower production rate.

Money Lost

Figure 6 compares money lost between excess power and reduction in production for the last seven consecutive years. Figure 5 shows a similar trend: the money lost due to both parameters was very high in 2014. On average, in the seven years, the money lost due to excess power consumption was estimated at roughly 4.4 million birr per year, whereas in the case of reduced production rate, it was around 15 million birr per year. Hence, the money lost due to the lower production rate was 3.5 times higher than that lost due to excess power usage.

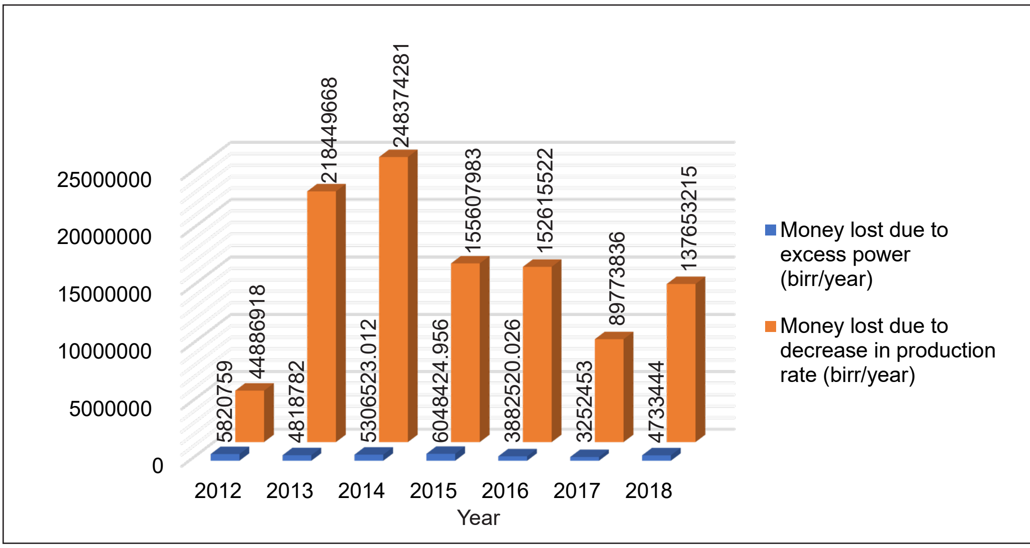


Figure 6. Variation of money lost for seven consecutive years

Profit Analysis

Figure 7 portrays the expected profit, actual profit, and money lost every seven consecutive years for the Messebo plant. The factory's cash profit depends on the cement factory's performance and may be affected by other factors. The expected profit is always constant at about 0.44 million birr per year, but the actual profit is always less than the expected profit, and it varies from year to year, as shown in the chart. On average, the actual profit was calculated to be around 0.29 million birr per year, whereas in the case of money lost, it was estimated to be 0.15 million birr per year. The maximum reduction in actual profit is observed to be about 33.3% compared to that of expected profit.

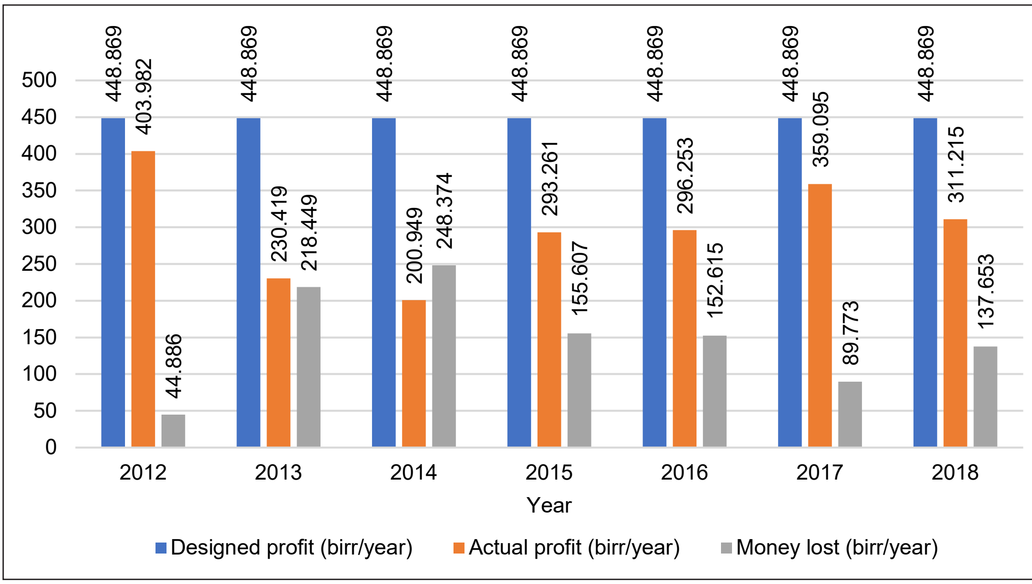


Figure 7. Profit description chart for seven consecutive years

Efficiency Analysis

Figure 8 represents the power usage and production rate efficiency for the last seven consecutive years. The rated specific power consumption was recorded as 33 kWh per ton, as taken from the Messebo plant manual. Power usage is the ratio of actual power usage to designed power usage. Similarly, production efficiency describes the ratio of the actual production rate to the designed production rate. In 2012, there was a significant improvement of about 90% compared with other consecutive years, whereas p usage was

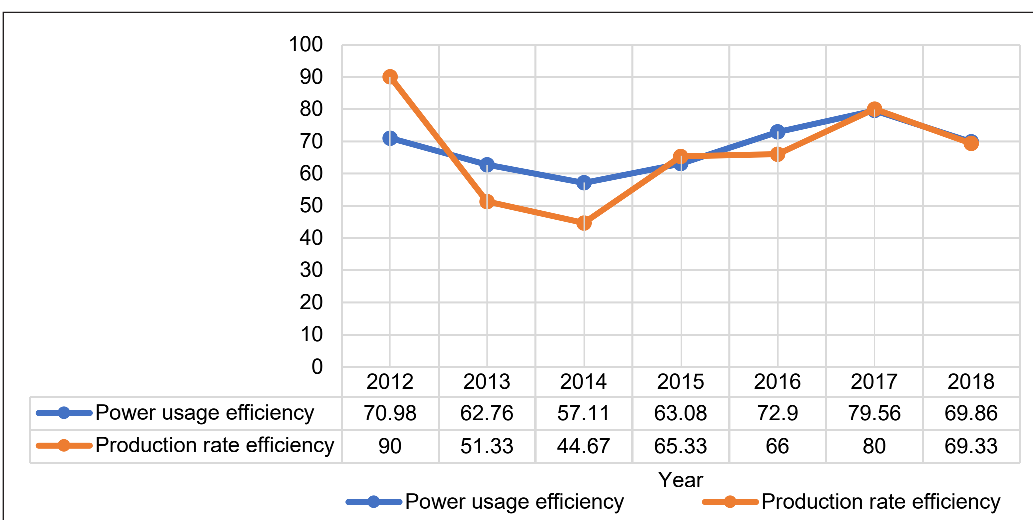


Figure 8. Power usage and production rate efficiency of cement factory

less than 0%. In 2014, there was a substantial reduction in production rate and power usage, about 45% and 57%, respectively.

CONCLUSION

Messebo cement factory has two production lines: Lines 1 and 2. However, in Line 2, there are two cement plants in operation condition, and this analysis was carried out for one mill only. Since both mills have been designed similarly, the power usage and production rate should be the same. This study evaluates the last seven successive years of the actual and designed value of production rate and power consumption usage. Some of the significant conclusions and the results of the present investigations are presented below:

- As we have seen in the power consumption analysis part, the average value of actual and rated power usage in the cement plant is 40.43 million kWh per year and 27.72 million kWh per year, respectively.
- The utilization of power consumption was less, around 32%, compared to rated power usage. It can be increased by proper scheduling to minimize the maintenance period.
- Money lost due to excess power consumption was estimated at roughly 4.4 million birr per year due to improper use of power in the plant. However, on the other side, a reduction in the production rate was determined to be around 15 million birr per year, 3.5 times higher than the money lost due to excess power usage.
- The actual profit was around 0.29 million birr per year, whereas in the case of money lost, it was estimated at 0.15 million birr per year.
- A significant improvement of about 90% can be seen in 2012, and for power usage, it is found to be less than 70%. There is a substantial reduction in production rate and power usage, about 45% and 57%, respectively.
- In 2014, the production rate was drastically reduced by almost 56%. It may be due to more showdowns happening in the plant. In order to improve the production rate, periodic maintenance shall be carried out in Lines 1 and 2.

ACKNOWLEDGEMENT

The authors acknowledged Mr. Gebrehiwet Gebremedhin, who was heading the center of excellence in the Messebo cement factory, permitted the research and supported us in using the facilities throughout the study period.

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Nomenclature

P_a	actual power consumed
P_e	excess power consumed
P_s	designed power consumption
Pr_a	actual production rate
Pr_d	reduced production rate
Pr_s	designed production rate
Ɐp	power usage efficiency
Ɐpr	production rate efficiency
i	indicates for specific year
n	total number of year