Energy Efficiency Analysis in a Textile Company Using DMAIC Approach

S Sakti, B M Sopha*, E S T Saputra

Industrial Engineering Program, Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada (UGM), Yogyakarta, Indonesia

Abstract. Textile industries generally consume a significant amount of electricity in their business operations, hence, efforts to reduce their consumption is necessary. This study assesses the energy consumption and energy saving opportunities in a textile company in Indonesia. A structured energy audit using Define-Measure-Analyze-Improve-Control (DMAIC) was implemented in the Spinning department. The evaluation indicates that 80% of the Specific Energy Consumption (SEC) are dominated by the factory air conditioner and chiller which is corresponding to 515 kWh/kg and 219 kWh/kg respectively. The Coefficient of Performance (COP) of the plant cooling system is 7.41 which conforms to the COP national standard. Further energy-saving opportunities include closing the door and other gateways of the air, replacing the refrigerant material from Freon R-134 to Musicool Mc-134, and installing inverter on mist nozzle motor, evaporator pump, condenser pump, and cooling tower.

1. Introduction

Energy plays an important role for industrial growth [1]. Textile has been the one that takes a significant share of energy in the industrial sector [2]. Several countries have put great attention to their textile industries, as in the case in Indonesia where textile has been placed in the top five prominent industries, which devote high proportion to the country’s income with the most energy consumption [3].

Company XYZ is the leading textile industry in Indonesia with large and diversified customers across the world. Despite its competitive advantage, the company is still facing challenge in term of energy efficiency –especially electricity. This issue can be examined from an upward trend in Specific Energy Consumption (SEC) of their Spinning department during 2016, with an average value of 3.2, whereas the maximum standard value of SEC by a Spinning industry is at 2.66 [4]. The smaller SEC, the better energy management. This therefore encourages an energy audit to evaluate how the energy consumed at the company XYZ.

Literature review investigated that the research related to energy audits have been widely conducted in various types of industries including textile. Six sigma Define-Measure-Analyze-Improve-Control (DMAIC) has been performed as one of the tools. However, previous studies integrating the relationship between energy efficiency, waste, and economic consideration are rare. This study therefore provides DMAIC framework to assess energy consumption in a textile industry, particularly in Spinning department. The present study identifies the waste in the production process.
and determines the energy saving opportunities considering economic feasibility, aiming to increase its energy efficiency.

The remainder of this paper is structured as follows. Section 2 summarizes the related literature, particularly that on energy audit in textile industry. Section 3 describes the problem and the system characteristics. Section 4 explains the six sigma DMAIC as the method. In section 5, the case study analysis is presented. Section 6 finally provides the conclusions and suggestions for future works.

As textile industry comprises lengthy process in a large number of plants, energy consumption in a textile and/or clothing industry has been thought to be worthy of investigation. [5] conducted an energy audit in the spinning subsector of textile industry in Pakistan. The study highlighted the importance of green infrastructure to improve energy efficiency in air conditioning units. [6] assessed energy consumption in a textile mill in Himachal Pradesh, India. A replacement of old/faulty ring frame motors with new energy efficient motor was possible for saving of energy, cost, and CO2 emission with less payback time. [7] investigated energy consumption of plants producing knitted garments in Turkey. The study was done using SEC calculation under an unstructured common work flow. Energy saving potentials were also provided. Similar to [7],[8] presented the steps of energy audit implementation in textile industry, however detail calculation was not provided. [9] performed energy management system using the ISO quality management system's philosophy of Plan-Do-Check-Action (PDCA) in a local textile plant in Egypt. Several improvement actions with the highest to the lowest cost savings were efficient lighting systems, compressed air leak removal, inefficient pumps replacement, and steam condensate recovery.

Unlike the aforementioned studies, [10] used Lean Six Sigma DMAIC approach to improve energy efficiency using a pharmaceutical company in Jordan as a case study. Since DMAIC performed well to examine the product quality [11,12], the use of DMAIC approach for energy audit is captivating. DMAIC provides a systematic approach for energy management process and guideline for effective system implementation [10]. [13] used Pareto Chart method –as one of quality improvement tools- to map waste in the textile spinning industry in Bangladesh. Solutions for energy efficiency were proposed without any economic impact analysis.

Summarizing, it appears that energy audits may be done using various tools including Six Sigma DMAIC. However, the use of DMAIC framework for energy audits is still lacking particularly in textile industry. Company XYZ is an integrated company that manufactures textile products ranging from yarn, raw fabrics, finished fabrics, and apparel. The production processes are carried out in four different departments: Spinning, Weaving, Finishing, and Garment. Besides being a starter –which is critical for the subsequent processes, the Spinning department contributes the most revenue to the company by 38.3% but consumes high electricity. It is therefore a great opportunity to do the further energy analysis. This study has mapped the production activities in the Spinning department that contribute to energy consumption and identify energy saving opportunities. The dominated energy consumption in the Spinning department is electricity. The Spinning department operates 24 hours in 7 days. The Ne 30’s Rayon yarn production is recorded as the input. Due to the resource limitations in this study, the DMAIC is carried out to the improve “I” stage. The results of this study are expected to help company XYZ and textile industry in general to realize waste and be able to save energy.

2. Methodology

DMAIC stands for Design, Measure, Analyze, Improve and Control. This framework came along with the concept of Six Sigma to improve business processes continuously [14]. The following provided framework is used as the guidance for employing DMAIC in this study. As the process is limited to “I”, Figure 1 displays the framework consisting Define, Measure, Analyze, and Improve, along with the observed objects. Several Six Sigma tools according to [14] are performed.
The “D” stage in this study is done by clarifying the production process flow and energy flow to support the production process. The waste generated in each process is also identified. Having a big picture of the whole process, the problem quantification is held in the “M” stage. At this stage the data regarding the production flow, the energy needed to carry out the process, processing time, and the resulting waste is collected. Both direct observation and secondary data collection are conducted. Employees are also involved in defining the critical waste as the main problem to solve. Continuing to the “A” phase, the data collected is analyzed to identify the root causes. Value Stream Mapping (VSM), Fishbone diagram, and Pareto chart are employed. Finally, the “I” stage is defining the potential improvement actions. It is worth noting that the energy saving opportunities are proposed under economic feasibility analysis.

3. Results and Discussion
This section provides the detailed explanation of the DMAIC stages conducted in the Spinning department in company XYZ.

3.1. Define
This stage observes that there are eight main processes in the Spinning department. The process is started with Mixing and Blowing process (i). Mixing is the stage of mixing the material with a bale setting based on the date of the raw material. This process uses a multi mixing machine to decompose and mix the fibres so that an even mixture will be obtained according to the product specification standards. Meanwhile, blowing refers to the process of extracting raw materials that have been arranged lengthwise in one line, involving 2 blowers. It then continues to Carding process (ii) which aims to convert the fibre into sliver. The sliver is then processed by a Draw Frame Breaker (iii) in the third stage which serves to bundle 7 slivers can from the carding machine to obtain uniform results, where each machine has two deliveries. The fourth stage is Drawing Finisher (iv). Similar to Drawing Breaker, Drawing Finisher consolidates 6 slivers can from the Drawing Breaker machine to produce a uniform sliver but has only one delivery. The next step is Speed Frame (v) which transforms sliver to roving. Roving is a large or coarse thread. The drawing cans are arranged in a row and then rolled and twisted into a bobbin to roving. The roving is then converted into threads (cops) and makes thread according to the expected standard in Ring Spinning or Ring Frame process (vi). Next, the Winding process (vii) change the cop-cops produced from the ring spinning process into cones. Each cone requires 27 cops of yarn where one cone weighs 1.89 kg. The Steam process (viii) is then run using a SIEGER machine which aims to control the moisture content of the finished yarn. Steam temperature and duration settings depend on thread number. Finally, the cone will be packed using pallet, neutral carton, logo carton, or sack, according to the customer's request. Figure 2 maps the production process and the waste generated in each process.
Figure 2. Production flow

The Figure 2 shows that the production processes in Spinning department have various types of waste, relative to its raw material and the machine. It is also worth noting that the cooling system becomes crucial to maintain the output quality of each process.

3.2. Measure

Historical data of Rayon NE 30’s production in 2016 was gathered. Data on processing time by different machines in the Spinning department (hours), total electricity consumption of the plant (kWh/month), and types and amount of waste in the plant was collected. Based on these data, the SEC in each area was calculated.

3.2.1. Processing time. The Rayon NE 30’s production time is divided into three categories: Value Adding Activity (VA), Non Value Adding Activity (NVA), and Necessary Non Value Adding Activity (NNVA). This means to identify whether the production activities are valuable. VAs are activities that would increase the value of the product from a customer's perspective. NVAs do not result in value addition to the product. Therefore, NVAs should be eliminated. NNVAs do not also give more value to our products but are needed in the existing process. This activity is harder to remove in the short term, so it has to be set for long-term target. The production time is summarized in Table 1. It also implies that the required cycle time for running the production until the packing stage is 113,086 seconds or equals to 31.41 hours.

| Category   | Quantity | Total time (seconds) | Total time (hours) | Percentage |
|------------|----------|----------------------|--------------------|------------|
| VA         | 16       | 110,488              | 30.69              | 97.70%     |
| NVA        | 3        | 72                   | 0.02               | 0.06%      |
| NNVA       | 10       | 2,526                | 0.70               | 2.23%      |
| Cycle time | 113,086  | 31.41                |                     | 100.00%    |

3.2.2. Electricity distribution. The electricity supply for production in the Spinning department has a total power of 20 kVA and a transformer capacity of 2,500 kVA at a premium rate. The energy distribution in this department is divided for production and office areas. The percentage of electricity consumption in each station is explained through a Pie chart in Figure 3.
Figure 3. Percentage of electricity consumption in the whole Spinning department (left) and electricity consumption in production area (right)

3.2.3. Waste. Table 2 shows the waste generated in the Spinning department for Rayon NE 30’s, which is obtained through a direct observation.

### Table 2. Waste classification in the Spinning department

| No | Waste type       | Problem                                                                 |
|----|------------------|-------------------------------------------------------------------------|
| 1  | Defect           | Scrap in the form of flat strip, dropping, sliver, sorting left, hard waste, pneumatic, roving. |
| 2  | Overproduction   | Excessive yarn production                                               |
| 3  | Transportation   | Excessive transportation from Carding to Drawing Breaker               |
|    |                  | Excessive transportation from Drawing Breaker to Drawing Finisher       |
|    |                  | Excessive transportation from Drawing Finisher to Speed Frame           |
|    |                  | Excessive transportation from Speed Frame to Ring Spinning             |
|    |                  | Excessive transportation from Ring Spinning to Winding                 |
|    |                  | Excessive transportation from Winding to Packing                       |
| 4  | Waiting          | Bale that has been arranged must wait for the laydown process which takes 3 shifts |
|    |                  | Roving from Speed Frame waits to be processed in the Ring Spinning machine because Cones that have been moved to the Packing station must wait for the ongoing Steaming Engine setup for 10 minutes after maintenance |
|    |                  | Maintenance and scouring                                               |
| 5  | Inventory        | Raw material inventory                                                 |
|    |                  | Finished goods inventory                                               |
|    |                  | Solid waste inventory                                                  |
| 6  | Motion           | Manual packing process in large numbers                                 |
|    |                  | Can arrangement by operator                                            |
|    |                  | Can movement between rack by operator                                   |
|    |                  | A door between Winding and Packing that should be opened manually is considered as a |
| 7  | Over processing  | Redundant process                                                      |
|    |                  | Rewinding process                                                      |
|    |                  | Process repetition in the waste opener                                 |

Regarding the diverse types of waste (see Table 2), a survey is conducted to the workers in order to determine which waste is critical and needs future investigations. The results calculation using Borda
Count Method indicates that the most critical waste is “defect” with a percentage of 16.28%. As the defect refers to the solid waste, a further observation is done to list the amount of solid waste in each process, which is then plotted in the VSM in Analyze “A” stage (see Figure 4). This is done to see whether energy efficiency can be achieved by reducing the solid waste or not.

3.3. Analyze

This stage aims at investigating the factors that affect electricity consumption in the Spinning department. VSM and Pareto chart are used as the tools.

3.3.1. Value Stream Mapping.

In order to see the electrical energy efficiency of each equipment, a SEC calculation is performed (see Table 3). The greater SEC leads to the higher possibility of inefficiency in the process. A VSM (Figure 4) is then constructed to illustrate the flow of material and information in the department plant. It also displays the energy required for each process and the solid waste amount generated.

| Process/machine       | Electricity (kWh/batch) | Output (kg/batch) | SEC (kWh/kg) |
|-----------------------|-------------------------|-------------------|--------------|
| Blowing               | 19,405                  | 1,276.21          | 15.21        |
| Carding               | 10,007                  | 1,276.21          | 7.84         |
| Drawing Breaker       | 197                     | 135.86            | 1.45         |
| Drawing Finisher      | 109                     | 134.82            | 0.81         |
| Speed Frame           | 2846                    | 2,102.41          | 1.35         |
| Ring Spinning         | 190,169                 | 4,291.47          | 44.31        |
| Winding               | 12,807                  | 170.10            | 75.29        |
| Steamer               | 9,703                   | 840               | 11.55        |
| Chiller               | 183,960                 | 840               | 219.00       |
| Air conditioner (plant)| 433,120                | 840               | 515.62       |
| Lighting (plant)      | 581                     | 840               | 0.69         |
| Air conditioner (office)| 36                   | 840               | 0.04         |
| Lighting (office)     | 7                       | 840               | 0.01         |

The dashed line illustrates the relationship between SEC and the percentage of solid waste. The Steamer process has zero solid waste since it only regulates the moisture content of the yarn. The next process with the smallest percentage of solid waste is the Ring Spinning process. It consumes large electricity but generates large output. The whole process in the Spinning department has a solid waste percentage of less than or equal to 0.10%, except the Drawing Finisher process. It requires small SEC but generates the highest amount of solid waste. Those indicate that in the observed Spinning department, the lower SEC which means efficient energy consumption, the higher solid waste generated. However, the desired process is at the bottom-left of the graph (in Figure 5) because it has a small SEC as well as a small percentage of solid waste.

On the other hand, energy consumption per output in the Winding process is the highest even though the percentage of its solid waste and the processing time is small. According to the expert judgment, this may occur because of frequent rewinding. This includes over processing waste. To find out the cause of this rewinding process, a fishbone analysis is shown in Figure 6.
Figure 4. Value Stream Mapping of Rayon NE 30’s
From the depicted VSM, we can also see the relationship between SEC and processing time as well as percentage of solid waste as illustrated in Figure 5.

![Figure 5. Comparison between SEC, processing time, and solid waste](image)

The solid line in Figure 5 displays the relationship between SEC and processing time. It can be seen that the longest processing time occurs in the Blowing process which takes 20 hours to decompose 2 cotton lines. Its SEC consumption is also one of the largest. The length of processing time on a Blowing machine is caused by many factors. These factors need to be further identified to reduce processing time which is proportional to the energy consumption. A fishbone diagram in Figure 7 represents several factors that influence the processing time on the blowing machine according to the observations and discussions with the maintenance supervisor as the expert judgement.
Long Blowing Machine

Process Time

Man
- workers' ignorance of dead machines
- Pressure parameter input error

Method
- Delays in multi-mixer machine operation
- workers' ignorance of dead machines

Material
- Low quality material
- Material contamination
- Failure in supplier selection

Machine
- Engine off
- Lack of maintenance
- Power outages
- Dust filter clogging

Figure 7. Fishbone diagram for Blowing process

Figure 8 is constructed in order to see the relationship between SEC and the percentage of VA. As we understand that the energy used to run the production machine aims to provide added value to the processed raw materials. Figure 8 indicates that there is a tendency that the higher SEC, the higher percentage of Value Adding Activity. This shows that every energy expended adds value to the product. This implies that every energy released in the Spinning department has added value to the product.

Figure 8. Comparison between SEC and VA

3.3.2. Pareto analysis.

The previous analysis reveals that reducing solid waste does not lead to more energy efficiency. Consequently, a Pareto diagram is built over the whole Spinning department to see the main contributor of electricity consumption. A Pareto diagram in Figure 9 identifies 20% of the problems which have 80% impact on electricity consumption in the Spinning department.

The Pareto chart in Figure 9 shows that the cooling system in the Spinning department consisting air conditioner and chiller give 80% impact on electricity consumption. Interestingly, this finding is similar to ones that emerged from the earlier studies [1,5].
3.4. Improve
From the previous analysis, it can be seen that solid waste was identified as the critical waste. However, a higher solid waste generated tends to have the lower SEC which means the more efficient the energy consumption. It may be due to the larger output which leads to higher possibility of having larger number of solid waste. From the pareto analysis, there are two facilities that have the highest contribution to the SEC in the department: the factory air conditioner and chiller. There are 6 ACs installed for 8 process in the Spinning department: 1 in Blowing; 1 in Winding; 3 in Ring Spinning; and 1 for the remaining processes. The total cooling capacity is 1150 TR or equals to 4044 kW, while the total energy input is 546 kW. To find out the efficiency of the cooling system, a calculation of Coefficient of Performance (COP) is done by comparing the ratio of input and output. The COP was calculated to be 7.41 which is higher than the national standard SNI 6390-2011 of 6.05. It concludes that the installed air system is in accordance with the standard.

However, should energy saving be conducted, there are several opportunities: no cost, low cost, and high cost. Energy savings with no cost can be done by closing doors, windows, and vents in the production area so that hot air from the environment cannot enter the room. The next energy saving opportunity is changing the refrigerant. The current refrigerant in the Spinning department is R-134A or often called Freon. Despite R-134a already has better properties than other freon refrigerant materials such as R-22 because it is non-flammable and relatively stable, but R-134 still has negative impacts on the environment. We suggest to substitute R-134A with Mc-134 or often called Musicool-134. Mc-134 is an environmentally friendly hydrocarbon refrigerant. Substitution of refrigerant material from Freon to Musicool will also support the ISO 14001 Eco-Friendly Program. Musicool does not have Ozone Depleting Potential (ODP) and has low Global Warming Potential (GWP) value. The use of hydrocarbon refrigerants will save energy by around 20% to 45% [15]. A feasibility analysis of the refrigerant replacement is explained in table 4. The calculation assumes the smallest energy saving of 20%.

The benefit and cost calculations result in the payback period (PBP) of 2 months. The energy conservation program requires an investment to have PBP less than 3 years [16]. Hence, the refrigerant investment is feasible. The next energy saving effort is based on the guidebook made by China Energy Group which is supported by U.S. Department of Energy [17] in order to acquire greater energy savings through the addition of equipment at a relatively large cost. In this case, an inverter installation in AC and chiller is proposed. By installing an inverter, the motor can adjust its speed so that electricity consumption can be suppressed. In the AC system, the inverter may be installed in the Mist Nozzle motor. Meanwhile, the inverter for chiller may be installed in evaporator pump, condenser pump, and cooling tower. Tables 5 and 6 show the economic feasibility for 6 inverters in
AC and 3 inverters in chiller, respectively. According to the calculations, PBP of inverter in AC and chiller are 13 and 6 months, respectively. Thus, these solutions are feasible.

Table 4. Economic analysis of refrigerant replacement.

| Component | Value |
|-----------|-------|
| Benefit calculation | Electricity consumption per month (kWh) 298,540 |
| | Energy saving 20% (kWh) 59,708 |
| | Electricity cost/kWh IDR 1,250 |
| | Total saving per year IDR 895,620,000 |
| Cost calculation | Cost per 6 kg IDR 800,000 |
| | Replacement requirements (kg) 768 |
| | Total cost IDR 102,400,000 |

Table 5. Economic analysis of inverter installation in AC

| Component | Value |
|-----------|-------|
| Benefit calculation | Electricity consumption per month (kWh) 22,355 |
| | Energy saving 50% (kWh) 11,177 |
| | Electricity cost/kWh IDR 1,250 |
| | Total saving per year IDR 167,659,469 |
| Cost calculation | 1 unit inverter 15 kW IDR 14,950,000 |
| | 1 unit inverter 22 kW IDR 30,098,200 |
| | 4 unit inverter 30 kW IDR 127,490,000 |
| | Total cost IDR 172,538,200 |

Table 6. Economic analysis of inverter installation in chiller

| Component | Value |
|-----------|-------|
| Benefit calculation | Electricity consumption per month (kWh) 130,402 |
| | Energy saving 50% (kWh) 65,200 |
| | Electricity cost/kWh IDR 1,250 |
| | Total saving per year IDR 978,013,573 |
| Cost calculation | 4 unit inverter 75 kW IDR 356,502,000 |
| | 2 unit inverter 37 kW IDR 94,387,000 |
| | Total cost IDR 450,889,000 |

4. Conclusions
This study has demonstrated the use of DMAIC tool for energy audit in the Spinning department of a textile company. It appears that the biggest energy consumption is produced by the production process. However, 80% of SEC is produced by air conditioner and chillers in production plant.

The detailed analysis indicates the COP of the plant's cooling system has conformed to the standards in SNI 6390-2011. Thus, the major system replacement is not necessary. Other no-cost energy-saving interventions could be done by closing doors, windows and vents in the production area so that hot air from the environment cannot enter the room. Energy saving can also be done by replacing refrigerant material from Freon R-134a to Musicool M-134 hydrocarbon. This may result in savings which is equivalent to IDR 895,620,000/year. Inverter installation on the mist nozzle motor of
each AC and chiller –on evaporator pump, condenser pump, and cooling tower- can be taken into account to obtain energy saving about IDR 167,659,469/year and IDR 978,013,573/year, respectively.

In addition, when the production output is high, the SEC is high but the percentage of solid waste is small, and vice versa. In order words, the higher SEC, the higher processing time. The highest solid waste in this study is in the Drawing Finisher station which requires the lowest SEC, nevertheless, the greater SEC generates greater percentage of value-added activities. The further energy conservation program needs to consider this trade-off to get the ideal case of small SEC with small solid waste.

The results imply that closing the door and other gateways of the air, replacing the refrigerant material from Freon R-134 to Musicool Mc-134, and installing inverter on mist nozzle motor, evaporator pump, condenser pump, and cooling tower are potential interventions to increase energy-saving. Full benefits may be achieved by implementing Control stage of the DMAIC process, which can be further explored for future research. Finally, similar framework can be adopted to either the same company with different product or other textile company streamlining their energy consumption.

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