Energy Efficiency Monitoring in Textile Industries to Achieve GHG Emissions Reduction Target in Indonesia

Retno Gumilang Dewi¹,², Rias Parinderati¹, Iwan Hendrawan¹, M. Wisnu B. Dewantoro³, Wira Dharma Bayuwega¹
¹Center for Research on Energy Policy, Research and Innovation Building 3rd Floor, Institut Teknologi Bandung, Jl. Ganesha 10, Bandung 40132, Indonesia
²Chemical Engineering, Faculty of Industrial Technology, LABTEK X 4th Floor, Institut Teknologi Bandung, Jl. Ganesha 10, Bandung 40132, Indonesia

Corresponding author: gelang@che.itb.ac.id, gelangdewi@gmail.com

Abstract. Modelling is used to provide an outlook and evaluate scenarios related to energy efficiency potentials from end-user in various sectors including industrial sectors. The modelling tools used ExSS (Extended Snap Shot) and GAMS (General Algebraic Modelling System) as solver. Three scenarios were developed to envision Indonesia paths in energy savings potentials, namely business as usual (BaU or baseline) and two counter measure scenarios (CM 1 and CM2). Base year was set to year 2010, in line with NDC scenarios and projection. In the baseline scenario, it is assumed that in the future years (after 2010) there would be no increase in renewable energy utilisation and rise in electricity demands would be provided by coal and natural gas fired power plants. The economic structures that were incorporated in the model for the target year 2030, was assumed to have the same value as that of 2010’s. Accordingly, structures of energy demand in end-user sectors would not change from 2010. There would be no changes in share of transportation modes. Similarly of efficiency of equipment in household, commercial and industrial sector were also indifferent to that of the 2010 values. CM1 was developed to envision the development path to achieve energy savings through the implementation of more efficient energy technology in end-user. More efficient equipment or best available technology (BAT) were expected to be implemented in various sectors, however the penetration in industry was still 5% less than other sectors (household, commercial and transportation). At this rate, BAT penetration for household, commercial and transportation sectors could reach as high as 20%. CM2 was set to be more advanced in implementing the BAT. As much as 10% increased in BAT penetration was projected to be realised in each of end use sector, i.e., household, commercial and transportation. Although, the BAT penetration in industry sector was still 5% less than others, the BAT could rise up to 25% for industry and 30% for non-industrial sectors. Parallel with this measure, biofuel demands would also increase to 10% by force of strictly implementing regulation. Baseline scenario estimates of the total final energy demand has increased by 2.5 times, from 143,747 ktoe in 2010 to 364,627 ktoe in 2030. The associated GHG emission from the related energy consumption in 2030 was estimated to be around 1,642,009 Gg CO2e, which was higher by almost 4 times the GHG emission level in 2010 (416,530 Gg CO2e).

1. Introduction

1.1. Indonesia's Textile Industry Profile
In line with the development of industrial sector, the Indonesian textile industry plays an important role in the growth of the Indonesian economic. Aside from providing the basic necessities of life, the textiles industry has played a pivotal role through its contributions to the industrial sectors and the
Indonesian GDP. In 2010, textile industry contributed around 2.26% of the total Indonesian GDP and increased to 2.28% one year after. Furthermore, the performance of textile industry sector is predicted to increase with an average growth of 5.7%/year (BPS). In order to increase their performance and gain more contributions for the Indonesian economic, textile industry sector should have more concerns in solving their loads in production cost. Besides purchasing the raw material, energy cost is one of the major expenses that most textile industries encountered, in which around 15–25% of their operational expenses are from the energy (see Figure 1). As a reference, assessment result from Haisanbeigi [1] shows that textile industries in most textile production countries (Brazil, China, India, Italy, Korea, Turkey, and USA) use large amount of both electricity and fuels to operate their textile plants [2]. The cost of energy in these textile industries varies from 5% to 10% of the total operating cost. This share is much different if compared to the cost structure of the Indonesian textile industry, which is around 15 – 45%.

![Figure 1. Value added, contribution to GDP, and cost structure of textile industry.](image)

Textile industries in Indonesia can be classified based on the typical process into several sub-categories, namely fibre production (Manmade Filament, Manmade Staple and Natural Fibre), spinning, weaving or knitting, dyeing, finishing and garment. Spinning category is the most dominant in Indonesia, followed by weaving. However, these are not representatives of each production capacity. Based on the available statistics data from 2015 until recently, Indonesia textile production was relatively stable compare to the previous years. An extreme downfall on production occurred in 2012, in which the number of the total national textile productions steeply fall around -90% from the previous years. Surprisingly in 2013, Indonesian textile industries was able to survive and rebound, although still facing another free-fall (-63%) in 2014.

1.2. Energy Intensity, Energy Use and Efficiency Opportunity in Textile Industry

1.2.1. Energy Intensity. There is still insufficient data on energy intensity for textile industry in Indonesia. The closest thing to the term energy intensity in Indonesia's textile industry is the Ministry Industry Regulation to impose green industry standards for textile industry. Industry players were encouraged to meet green industry requirements to obtain green industry award from the ministry. The energy aspects of the green industry requirements covered threshold of electrical energy consumption, thermal energy consumption and GHG emission, per tonne of textile product, at 1100 kWh/tonne, 3500 kWh/tonne and 2.03 tonne CO₂/tonne respectively. As the green industrial standard was created not only to focus on energy aspect, the energy efficiency target was still underdeveloped. The criteria only cover half of the textile industry chain (printing, dyeing and finishing), whereas fibre making, spinning, and weaving were still excluded. The energy threshold seems oversimplified if it was compared to the benchmark of IFC (International Finance Corporation) as shown in Table 1. The electrical energy intensity criteria was in the range of yarn dyeing benchmark, the criteria, however, it was not able to capture possible lower electrical energy intensity of other dyeing and finishing processes. In terms of thermal energy, Indonesian standard is substantially lower than IFC’s, which presumed to be caused by the warmer annual average temperature in Indonesia.
Table 1. Comparison of energy intensity between Indonesia’s Green Textile Industry Standard and IFC-EHS Guidelines (kWh/ton textile product).

| Process                    | Indonesia’s Textile Printing, Dyeing and Finishing Green Industry Standard | IFC-EHS Guidelines Textile Manufacturing |
|----------------------------|--------------------------------------------------------------------------------|------------------------------------------|
|                            | Electrical Energy                                                                 | Thermal Energy                            |
| Wool scouring              | 300                                                                              | 972                                      |
| Yarn dyeing                | 800 – 1100                                                                       | 3611 - 4444                              |
| Dyeing loose fibres        | 100 – 400                                                                         | 1111 - 3889                              |
| Finishing knitted fabrics  | 1100                                                                              | 3500                                     |
| Finishing woven fabric     | 500 – 1500                                                                        | - 19444                                  |

1.2.2. Energy Usage in Textile Industry. The US DOE study on energy use, loss and efficiency opportunity across the US’s manufacture and mining industry in 2004 [3] is probably the most comprehensive study about energy use in textile industry by far. The study has successfully revealed the breakdown of energy consumption by end-use technology, as shown in Figure 2. Energy used in textile industry were dominated by fired heater and motor driven systems, where each accounted for 28% of the total consumption, followed by fired heater (20%), and facilities (18%). According to the technology, energy consumption for steam and fired heater were actually interchangeable as both were able to heat water and air, which formed the largest requirements for processing and drying process. In addition, it should be noted that the structure of textile industry in the US differed from Indonesia. US textile industry is less labour-intensive activity such as in spinning and weaving processes.

![Figure 2](image_url)  
**Figure 2.** Final energy end-use and breakdown of motor system use in the US textile industry [3].

The same study also showed the sources of energy losses in the US. More than half of the losses came from offsite (64%). Meanwhile, the motor system losses took account on 13% of the losses, the highest for the onsite losses. Other important sources of losses were distribution losses (8%) and boiler losses (7%). If the energy use is broken down in the motor system, it was observed that materials processing was responsible for 31% of the energy consumption. Pumps, compressors and fans also consumed significant amount of energy share, as much as 19%, 15% and 14% consecutively. In terms of production process, dyeing & finishing consumed the most energy. JICA study in 2009 [4] showed that 80% of the energy was consumed in dyeing & finishing, 8% accounted equally for each fibre making & spinning and knitting & weaving, whereas sewing & garments only consumed 4%. There were some differences in energy consumption profile among each textile production process, as described below:

- Fibre manufacture: Energy was used to manufacture chemical fibre such as viscose rayon, polyester, nylon and acrylic dominates by electricity. The manufacture process required spinning and circulating water and air, which required electricity. The process also consumed energy for washing and drying machine.
- Spinning: Most of energy used in spinning process occurred in the machines, largely to operate ring machines. Beside machines, spinning process also required good temperature and
humidity control, which caused the humidification plant also consumed significant amount of energy.

- Weaving: The energy consumption characteristics was similar to the spinning process. Warping, sizing and looming machine mostly required electricity. In addition, the process also required good room conditioning. Heating involved in weaving process was largely occurred in sizing machine.

- Dyeing & processing: Textile dyeing and processing required energy mostly from heat obtained from steam as well as combustion. Electricity also used in the process to operate machineries.

- Sewing: Process to cut and sews textile generally required electricity.

1.2.3. Energy Efficiency Opportunities in Textile Industry. JICA [4] identified as much as 30% of energy saving potential would be achievable in Indonesia by 2025 (Table 2). Such amount of energy saving could be achieved through energy conservation and efficiency activity in many processes from fibre making to fabric finishing. In order to identify the energy saving opportunities, it was important to begin from typical industrial activities in industry that were applicable to textile industry. The mind mapping process to develop the energy efficiency alternatives through textile production process is shown below in Figure 3.

**Table 2. Textile industry energy saving potential in Indonesia [4].**

| Year | Fibre making & Spinning | Knitting & Weaving | Dyeing & Finishing | Sewing & Garments | Total |
|------|-------------------------|--------------------|--------------------|-------------------|-------|
| 2015 | 2.50%                   | 2.50%              | 12%                | 0%                | 10%   |
| 2025 | 20%                     | 20%                | 35%                | 0%                | 30%   |

**Figure 3.** Possible mitigation options in the textile production process.

Literature study has provided deeper examples on energy efficiency activities in textile manufacturing process. Among the activities, super critical CO$_2$ dyeing system achieved the highest...
saving potential. However, the applicability of the system to industry is quite limited as it required huge investment as well as CO₂ source. The most replicable action could be installation of VSD/VFD that can be done in many machinery, pumps and fans. Utilisation of VSD/VFD might reduced the unit energy consumption up to 30%. Another important saving activity was the waste heat utilisation at stenter, dyeing machine and merceriser [5, 6, 7].

2. Methods
Energy, as the second largest sector of GHG emitters after agriculture, forestry and land use (AFOLU) was expected to significantly contribute to lower emission levels. Climate change mitigation actions in the energy sector included the use of renewable energy, improvement in energy equipment efficiency and energy conservation efforts, and substitution to low-emission fuels. To be able to determine emission reduction, it is essential to have an outlook on future projections.

2.1. Methodology and Assumption
Model simulation was used to deliver an outlook and evaluate scenarios related to energy efficiency potentials from end-users in various sectors including industry, household, commercial, transportation and power generation sectors. The modelling tool used ExSS (Extended Snap Shot) with GAMS (General Algebraic Modelling System) as the calculation software and solver.

ExSS was considered as a comprehensive calculation tool to provide following objectives, i.e.: i) Illustrate quantitative future snapshot of an area in question to evaluate the feasibility of the vision (low carbon society), ii) Analyse relationship between socio-economic conditions and environmental load, and iii) Define a portfolio of the measures to meet the environmental target. The structure of
ExSS is presented in Figure 4. The procedure in using the ExSS tool includes: (1) setting framework, (2) collecting base year information, (3) collecting low emissions measures information, (4) estimating snapshots without low emissions measures, and (5) estimating snapshots with low emissions measures.

2.2. Formulation of model

In ExSS, the energy demand at energy end-use sectors is calculated using the following formula.

\[
TCEF_{eds,esc,e,tc} = \frac{TCSV_{eds,esc,e,tc}}{TCED_{eds,esc,e,tc}}
\]

\[
ES_{eds,esc,e} = \sum_{tc} TCSH_{eds,esc,e,tc}
\]

\[
EF_{eds,esc,e} = \sum_{tc} \left( \frac{TCEF_{eds,esc,e,tc} \times TCSH_{eds,esc,e,tc}}{ES_{eds,esc,e}} \right)
\]

\[
ED_{eds,esc,e} = ESVD_{eds,esc} \times ES_{eds,esc,e} \times EF_{eds,esc,e}
\]

Where:
- \( TCEF_{eds,esc,e,tc} \): Energy efficiency of energy demand sector \( eds, \) energy service \( esv, \) fuel \( e, \) device \( tc \)
- \( TCSH_{eds,esc,e,tc} \): Device share energy demand sector \( eds, \) energy service \( esv, \) fuel \( e, \) device \( tc \)
- \( TCSV_{eds,esc,e,tc} \): Energy service supplied by device \( tc \) of energy demand sector \( eds, \) energy service \( esv, \) fuel \( e, \) (service supplied by \( TCED_{eds,esc,e,tc} \))
- \( TCED_{eds,esc,e,tc} \): Energy required for device \( tc \) of energy demand sector \( eds, \) energy service \( esv, \) fuel \( e, \) (energy required by \( TCSV_{eds,esc,e,tc} \))
- \( ED_{eds,esc,e} \): Final energy demand of energy demand sector \( eds, \) energy service \( esv, \) fuel \( e \)
- \( ES_{eds,esc,e} \): Fuel share of energy demand sector \( eds, \) energy service \( esv, \) fuel \( e, \) (\( \sum_{e} ES_{eds,esc,e} = 1 \))
- \( EF_{eds,esc,e} \): Fuel share of energy demand sector \( eds, \) energy service \( esv, \) fuel \( e, \) (\( \sum_{e} EF_{eds,esc,e} = 1 \))

What was essential in low carbon society is supplying sufficient energy service yet consuming less energy (improving energy efficiency) and emitting less GHG. Taking into account that energy service is the matter directly needed by consumer, the substantial in study utilizing ExSS is energy service. Driving forces of energy service in each end-user sector can be seen in the structure of ExSS as depicted in Figure 4. Economy input is also pivotal and obtained from IO table where the formulation involved inverse matrix of Leontief as follow.

\[
\sum_{j} \left( Imat_{ij} - (1 - IMR) \times Amat_{ij} \times Ainvi_{j,k} \right) = Imat_{ij,k}
\]

Where:
- \( Imat_{ij} \): Unit matrix
- \( IMR \): Import ratio of industry \( i \) (=import/ regional demand) [\( \text{ratio} \leq 1 \)]
- \( Amat_{ij} \): Input coefficient matrix (input coefficient to industry \( i \) from industry \( j \)) [\( \text{share}, \sum_{i} Amat_{ij} = 1 \)]
- \( Ainvi_{j,k} \): Inverse matrix of Leontief (Here, \( (1- (1-M) A) \)-1 type is applied)
- \( i,j,k \): industry (=pds)
2.3. Scenarios

Three scenarios were developed to envision Indonesia paths in energy savings potentials, namely business as usual (baseline) and two counter measure scenarios: i) CM1, for end use energy efficient technology penetration and ii) CM2, for the increased rate of energy efficient technology penetration combined with more renewable energy. Base year was set to year 2010, in line with Indonesia's NDC scenarios and projection. In the baseline scenario, it was assumed that in the future years, there would be no increase in renewable energy utilisation, and rise in electricity demand would be provided by coal and natural gas fired power plant. Economics structure in the target year of 2030 was assumed to be the same as that of 2010. Accordingly, structures of energy demand in end-user sectors would not change from 2010. There would be no change in share of transportation modes. Similarly, efficiency of equipment in household, commercial and industry sector were in different to those of 2010.

As aforementioned, CM1 was developed to envision the development path to achieve energy savings through the implementation of more efficient energy technology in end-user, hence more efficient equipment or best available technology (BAT) were expected to be implemented in various sectors. However, the penetration in industry was still 5% less than other sectors (household, commercial and transportation). At this rate, BAT penetration in each household, commercial and transportation sectors could reach as high as 20%. In addition, biofuel would substitute 5% of the fossil fuels consumed on account of availability of blended fuels in the market was still limited to 5% biofuel-95% diesel oil. CM2 was set to be more advanced in implementing the BAT. As much as 10% increased in BAT penetration was projected to be realised in each of end use sector, i.e., household, commercial and transportation. Although the BAT penetration in industry sector was still 5% less than others, the BAT could rise up to 25% for industry and 30% for non-industrial sectors. Parallel with this measure, biofuel demand would increase to 10% by force of strictly implementing regulation.

Summary of some parameters assumed in the model is presented in Table 3.

| Table 3. Assumed parameters in the model. |
|-----------------------------------------|
| Parameters | Baseline | CM1     | CM2             |
| GDP growth | 5.5%     | 5.5%    |                 |
| Economics structure | Economic structure in 2030 is the same as that of 2010 | Following RUPTL and more renewables |
| Share of energy in power | Share of energy in 2030 is the same as that of 2010 | Following RUPTL |
| Share of transportation modes | Share of transportation modes in 2030 is the same as that of 2010 |
| Efficiency | Efficiency of equipment in 2030 is the same as that of 2010 |
| BAT penetration | 15% in industry, 20% in household, 20% in commercial and 20% in transportation | 25% in industry, 30% in household, 30% in commercial and 30% in transportation |
| Biofuel | 5% | 10% |
| Others | kerosene is phased out |

*RUPTL : general plans of power generation issued by state owned electricity company

3. Results

3.1. Result of Model Simulation for Projecting National Energy Demand

Baseline scenario estimated the increase of total final energy demand by 2.5 times, from 143,747 ktoe in 2010 to 364,627 ktoe in 2030. The associated GHG emission from related energy consumption in
2030 was estimated to be around 1,642,009 Gg CO2e, an increase by almost 4 times that in 2010 (416,530 Gg CO2e). This major raise was due to the domination of coal and oil shares in energy mix.

3.2. **Result of Model Simulation for Projecting National Energy Demand in Industry Sector**

Energy demand in industrial sector has experienced more substantial increase where it was estimated to rise up to almost 3.3 times, from 56,154 ktoe to 184,392 ktoe (see **Figure 6**). Corresponding to that, the GHG emission would also increase from 144,802 Gg CO2e to 523,221 Gg CO2e (3.6 times).

3.3. **Result of Model Simulation for Projecting Textile Industry Energy Demand**

Energy demand in textile industry has experienced a similar increase as has the industrial sector (see **Figure 7**). Under baseline scenario, it was estimated to increase almost 3.3 times from 424 ktoe to 1,382 ktoe. Corresponding to the energy consumption, the GHG emission would increase from 993 Gg CO2e to 3,373 Gg CO2e (3.6 times).
abundance availability. Through implementing mitigation measures in CM1 and CM2, the energy demand would be reduced by 3.5% and 5.9% consecutively (see **Figure 8**).

![Energy demands by type in baseline and mitigation scenarios.](image)

**Figure 8.** Energy demands by type in baseline and mitigation scenarios.

As has already been mentioned, coal in textile industry made the highest portion of energy consumption. In baseline scenario for textile industry, coal was majority burned for fuelling boiler generating steam (366 toe) and providing direct heat (355 toe) in 2030. By implementing CM1, coal consumption for generating steam would decrease to 360 toe (by 1.6%), while coal for direct heat would be declined to 333 toe (by 6.2%), giving the total coal consumption of 693 toe or 3.9% less than BAU. Practising CM2 measures would extend the reduction of coal consumption to 6.2% below the baseline consumption. Based on CM2 results, coal consumption for direct heat was reduced by 9.8% (become 320 toe) and declined by 2.7% (become 356 toe) for generating steam. Energy reduction from measure applied in direct heat system was greater than that in boiler technology, indicating that direct heat generation technology could achieve higher efficiency.

Oil made slightly less than 5% of the energy consumption in textile industry. Oil was used as fuel in direct heat, motor driver and other equipments. Energy savings achieved in CM1 was 2 toe lower than the baseline consumption. Greater savings in energy was the result of the implementation of CM2, which was 5 toe lower than the baseline consumption. Gas was delivered to textile industry usually through piping system, then it would be burned as fuel, as in the case of coal, for generating direct heat and steam. Natural gas consumption in textile industry was approximately 2.5 times higher than oil and was likely to be used for the same purpose of coal, i.e. provided direct heat and generating steam. The impact of efficiency efforts would deliver relatively similar results as that of coal. CM1 could decline gas consumption by 5.4% from direct heat and 1.1% from steam generation. CM2 could reduced gas consumption by 9.4% from direct heat and 2.2% from steam generation.

Electricity was supplied by grid (electricity company/PLN) and by captive power (industry owned generation). Electrical energy was the second major source of energy in textile industry and based on the baseline scenario, the amount consumed would reach 429 toe in 2030. Electricity consumption was addressed to equipment for direct heat (10%), steam generation (2%), motor driver (17%), and other (4%). CM1 was able to reduce the total electricity usage from 429 toe to 415 toe and CM2 could further decrease to 407 toe. Efficiency efforts in motor driven equipment has make great impacts in energy savings since the achievement of energy reduction could reach 11 toe in CM1 and 17 toe in CM2.
The following bar graphics showed the equipment consuming energy (see Figure 9). The energy was used largely to supply direct heat (493 toe), generate steam (489 toe), to move motor driven equipment (336 toe) and the rest was used to activate other equipments (63 toe). Efficient equipment for direct heat derived significant impact in terms of percentage of energy savings. Result of CM1 showed that an efficiency in direct heat technology would provide energy savings from each energy sources in the amount of 22 toe (coal), 1 toe (oil), 4 toe (gas) and 2 toe (electricity). CM2 gives greater savings that is equal to 35 toe (coal), 2 toe (oil), 7 toe (gas) and 4 toe (electricity).

Figure 9. Energy demands by type of equipment in baseline and mitigation scenarios.

With regard to efficiency in steam generation technology, CM1 showed that energy savings from each energy sources were in the amount of 6 toe (coal), 1 toe (gas), and insignificant amount of toe (electricity). Meanwhile, CM2 gave greater savings that was equal to 10 toe (coal), 2 toe (gas) and insignificant amount of toe (electricity). Result of CM1 for efficiency in motor driven equipment showed that energy savings were generated in the amount of 11 toe (electricity) and 1 toe (oil). Meanwhile, CM2 gave greater savings that was equal to 17 toe (electricity) and 2 toe (oil). The model results for efficiency for other equipment showed that under CM1, the electricity savings accounted for 1 toe, while oil consumption decreased insignificantly. Further results of other equipment efficiency under CM2, electricity and oil consumption dropped to 57 toe and to 4 toe respectively, denoting savings for each energy was 1 toe.

4. Conclusion
Since textile industries have large contributions to the national GDP and exports, these industries must meet competitive international markets. Therefore, supporting these type of industries to increase their energy efficiencies, at least to achieve an energy intensity as similar to industries of other countries would also help to reduce the cost of production. It should be noted, the energy cost in Indonesian textile industries accounted for 15-25% of the total production cost whereas the cost of similar industries of other countries only accounted for 5% of total production cost. There are still rooms for improvement in energy efficiency in textile industries. JICA study (2009) shows that energy savings potential in textile industry can rise up to 30%, whilst this study assumes BAT penetration at 15% (CM1) and 25% (CM2). From the ExSS results of textile industry, the efficient technology in direct heat contributed the biggest GHG emission reduction followed by efficient motor equipment.
Acknowledgement
Support from National Institute for Environmental Studies (NIES) Japan, Centre for Research on Energy Policy-Institut Teknologi Bandung (CREP-ITB) Indonesia to carry out the study is highly appreciated.

References
[1] Hasanbeigi, A. 2010. Energy Efficiency Improvement Opportunities for the Textile Industry. Ernest Orlando Lawrence Berkeley National Laboratory.
[2] Bureau of Energy Efficiency, Government of India. 2015. Normalization Document and Monitoring & Verification Guidelines Textile Sector.
[3] US DOE. 2004. Energy Use, Loss and Opportunities Analysis: U.S. Manufacturing and Mining. U.S. Departement of Energy.
[4] JICA. 2009. The study on Energy Conservation and Efficiency Improvement in The Republic of Indonesia. Japan International Cooperation Agency
[5] Ganesan, P. (2015). Investigation of potential reduction in energy consumption and CO2 emission in process industries. Page 66.
[6] Umwelt Bundes Amt (2011). Environmental Standards in The Textile and Shoe Sector. A Guideline On the Basis of the Brefs - Best Available Techniques Reference Documents of the EU, 13.
[7] Susanti, T. (2017). Developing Competitive Sustainable Manufacturing in the Indonesian Textile Industry. Duke University.