

The Road to Energy Efficiency in the Textile Industry: Key Challenges and Practical Solutions

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Abstract: - Small and medium-sized businesses (SMEs) dominate the textile industry, which is a diverse and fragmented industrial sector. Even though every textile business has numerous potential to increase energy efficiency, these affordable solutions are frequently not used because there is little information about their application. The purpose of this study is to present comprehensive data on energy usage, technology, and energy-saving strategies appropriate for the textile sector. When accessible, it includes information on energy costs and savings along with a case study from a Casablanca textile business. A brief summary of the textile industry is also given in this study, along with an analysis of the kind and proportion of energy consumed in various textile operations. In some, the potential for increasing energy efficiency is highlighted. This paper's objective is to demonstrate that there is a wide range of energy efficiency measures for the textile industry, most of which have a relatively short payback period. This means that investments in these measures can generate significant and rapid energy savings for textile factories while contributing to a reduction in their environmental impact.

Key-Words: - Energy consumption- Energy efficiency- Energy-saving technologies- Motor systems- Process modernization and optimization- Energy cost reduction- Environmental impact- Sustainable production-small and medium enterprises (SMEs)

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1 Introduction

Despite being a well-known term, industry 4.0 still lacks sufficient foundational scholarly understanding. Therefore, not everyone is aware of what Industry 4.0 actually means, and there is a lack of knowledge about it. Just 48% of the 300 manufacturing industries examined in January 2015 said they were considering deploying Industry 4.0. Industry 4.0 is still being used in fewer industries. Although they are aware that Industry 4.0 will benefit a business, they are still unsure of the primary effects, [1].

The intricacy of the textile industry sets it apart. The large range of substrates, procedures, equipment, and parts utilized, together with the several finishing stages required for production, are the causes of this complexity.

In this regard, energy is one of the primary cost components for the textile sector, particularly during periods of fluctuating energy prices. Consequently, increasing energy efficiency has emerged as a key issue for textile mills.

Nevertheless, despite these energy-saving possibilities, textile mills rarely adopt many

affordable choices, mostly because there is a dearth of knowledge about how to do so. Because they lack the means to learn about energy-efficient technologies and practices, SMEs are most affected by this issue.

By gathering data on energy usage in the textile sector and identifying various energy-saving techniques and technologies, this study carried out a thorough literature analysis. To give this research a strong foundation, more than 70 references were examined, [2].

Even though energy is crucial to the textile industry, there aren't many published scientific studies that focus on the particular energy problems facing this sector. A small number of studies have examined the energy savings attained through particular energy efficiency methods, including those carried out in Taiwan, Germany, Colombia, and Turkey.

Energy efficiency in the textile industry has been the subject of numerous research. They suggest best practices for specific textile industry production procedures.

This document is notable for its comprehensive list of 70 cross-cutting strategies that apply to all areas of the textile industry and its clear perspective of energy usage in this sector.

2 Problem Formulation

Few published scientific studies concentrate on the particular energy difficulties affecting the textile industry, despite the fact that we all know how important energy is to this sector. In addition to a list of sectoral and cross-cutting energy efficiency technologies and initiatives for the textile industry, some of them offer best practices and advice for certain textile dyeing and finishing procedures, [3].

The textile industry confronts significant obstacles in the context of Industry 4.0 because of its high energy consumption and intricate operations, which range from spinning to fabric treatment. These procedures require a lot of energy, which raises expenses, particularly for SMEs, who control the majority of the market. The textile industry continues to underutilize Industry 4.0's cutting-edge solutions for increasing energy efficiency through automation, connectivity, and real-time data analysis. Cost-effective energy measures are crucial for lowering expenses and their impact on the environment, but their implementation is frequently hampered by a lack of knowledge and resources.

In this context, it is crucial to identify and promote accessible, tailored technological solutions for SMEs, enabling them to fully benefit from Industry 4.0 advancements to optimize energy consumption and enhance competitiveness.

2.1 Method

From processing raw materials to semi-finished goods (yarns, knitwear, and finished fabrics) and certain finished goods (knitwear, home linen, décor, etc.), the textile industry encompasses the entire manufacturing cycle. The textile industry does not view clothing as an essential component. There are multiple steps involved in turning textile raw materials into completed goods: the fibers are first turned into yarns, which are subsequently turned into fabrics (either by knitting, weaving, or non-woven methods). The fibers go through a number of finishing processes during the transformation, including bleaching, dyeing, printing, and finishing. The textile business uses a wide variety of procedures, too many to describe in the space allotted in this document. Consequently, the following lists the primary textile processes that are

discussed in this document. These are the most significant and responsible for the majority of the energy used in the textile sector shown in Figure 1:

- Yarn spinning
- Weaving
- Wet processing (preparation, dyeing, printing, and finishing)
- Production of artificial fibres

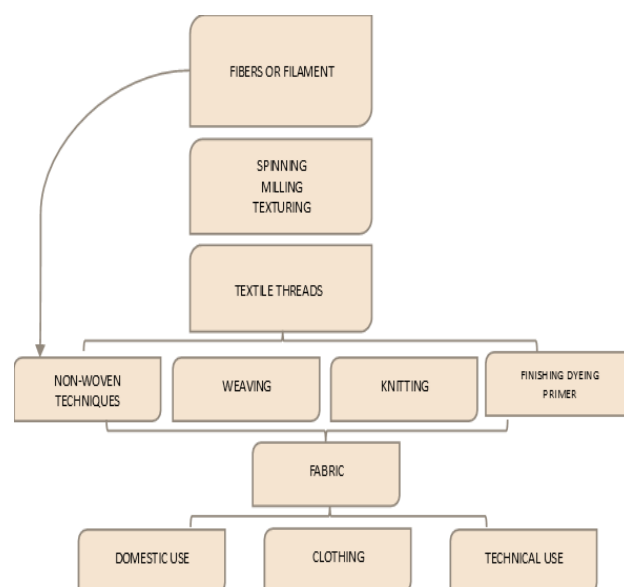


Fig. 1: The Textile Chain, [4]

2.1.1 Distribution of Energy Consumption by End Use

Activities differ significantly in their energy requirements and how fossil fuels and electrical energy are distributed as shown in Figure 2. For instance, there is a noticeable difference between spinning with motive power requirements (mechanical treatment of materials) and finishing with mostly thermal needs (heated baths, drying, etc.). It should be mentioned that, depending on energy prices, electricity may account for a higher percentage of the energy bill than the energy balance.

Separating energy use between production and, on the one hand, building heating and cooling is another method of addressing the variety of activities in the textile sector. The bulk of energy use is directly related to the process, and in some activities, like finishing, where warm baths and drying fabrics are common, it can exceed 90%. Workshop air conditioning uses energy more specifically for spinning and weaving.

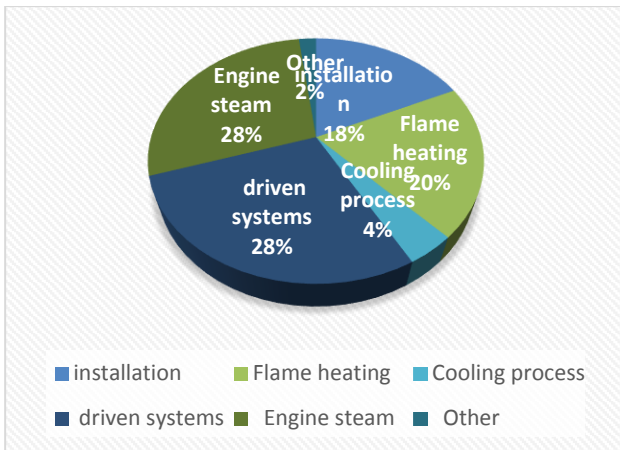


Fig. 2: Final energy use in the textile industry, [5]

2.1.2 Distribution of On-Site Energy Losses for the Textile Industry

The energy losses were estimated using factors applied to various industrial equipment, based on sources and expert opinions. The most significant losses involve material processing (90%), compressed air (80%), and internal transportation (50%). Steam systems lose around 55%, whereas electricity production is more efficient through cogeneration (24%), compared to traditional methods (45%). Energy distribution remains the most efficient (3% loss). These data show a significant potential for energy savings in industry.

Table 1. On-site energy loss profile for the textile industry, [6]

Energy System	Percent Energy Lost
Steam systems	Boilers – 20%
	Steam pipes and traps - 20%
	Steam delivery/heat exchangers – 15%
Power generation	Combined heat and power – 24% (4500 Btu/kWh) Conventional power – 45% (6200 Btu/kWh)
Energy distribution	Fuel and electricity distribution lines and pipes (not steam) – 3%
Energy conversion	Process heaters – 15% Cooling systems – 10%
	Onsite transport systems – 50%
	Electrolytic cells – 15% Other – 10%
Motor systems	Pumps – 40% Fans – 40%
	Windings – 5% Compressed air – 80%
	Refrigeration – 5%
	Materials handling – 5% Materials processing – 90%

2.1.3 Distribution of Energy Consumption of Motorization Systems in the Textile Industry

Because of their impact on the sector in terms of energy consumption, motorization systems were

naturally the focus of our study orientation. As was already noted, one of the primary causes of energy waste in the textile sector is motor systems. Figure 3 shows how these systems' energy usage is distributed across the different textile industry processes. Notably, 31% of the energy consumed by motor systems comes from material processing, with pumps, compressed air, and ventilation systems coming in second and third, respectively, at 19%, 15%, and 14%, [7].

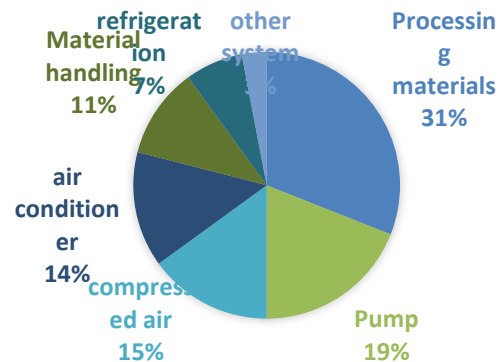


Fig. 3: Distribution of energy consumption of motorization systems in the textile industry, [7]

3 Problem Solution: Possibilities for Improving Energy Efficiency in the Textile Industry

The possibilities for process modernization and optimization as well as the total replacement of existing machinery with new, cutting-edge technology are the main topics of this study on the potential for increasing energy efficiency in the textile sector. The energy efficiency of the machines cannot be increased due to the large initial investment prices of new state-of-the-art technologies, so special emphasis is given to modernization measures.

The expense of the process alone is frequently not justified by the savings that come from replacing old equipment with new. But if we consider all the advantages that come with using new technology, including reducing waste and wastewater, saving water and materials, lowering rework, improving product quality, etc.

Furthermore, we have attempted to provide actions for which we might determine quantitative costs and energy savings. However, in certain cases, we could not discover such quantitative values, but since some measures are already well known for their energy-saving value, we chose to include them in the paper (Figure 4) despite the lack of quantitative measures of their potential. We think

that engineers working in textile mills can find ways to increase energy efficiency by being aware of these technologies and procedures.

It should be mentioned that the cost and energy savings information in this document is either mill/case specific or typical. A number of variables, including mill and process specifics, fiber, yarn, or fabric type, raw material quality, final product, and raw material specifications, the mill's location, etc., may affect the savings realized and the cost of the measures. For instance, labor expenses account for a large amount of the cost of some energy efficiency measures, hence the price of these measures might differ greatly between industrialized and developing nations.

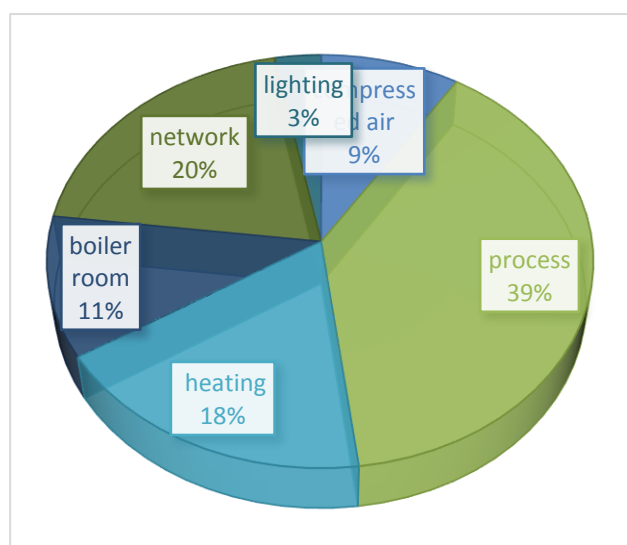


Fig. 4: Overall energy saving potential by end-use sector, [8]

4 Problem Solution: Energy Efficiency Measures

Cross-cutting energy efficiency technologies and measures are included in Table 1. A comprehensive strategy that incorporates pumps, compressors, and fans is necessary to increase the energy efficiency of a plant's drive systems and optimize performance and energy savings. The following details a driving system's energy usage and potential savings, some of which are supported by specific examples.

Compressed air, ventilation, and pumping systems are also covered, in addition to electric motors. A large portion of the final energy consumption is accounted for by steam systems, which are frequently found in textile mills. Significant energy savings and increased productivity can be achieved by optimizing boiler efficiency and recovering excess heat.

Additionally, common opportunities to enhance textile manufacturing and distribution performance in industrial plants are described. Each of the energy efficiency measures or technologies included in this work is described in detail in references.

The energy savings, costs, and payback times mentioned in the table apply under certain specific conditions. Implementing certain actions also offers secondary benefits. Please refer to the explanation of each action for a complete understanding of the savings and costs (Table 2, Appendix).

4.1 Model Validation and Sensitivity Analysis

Validation of the mathematical models was done to ensure the accuracy and dependability of the MCDM techniques (MABAC, MOORA, and MAIRCA) employed in this investigation. The statistical metrics that are frequently used to assess the effectiveness of prediction and ranking models serve as the foundation for this validation.

The following actions have been taken:

- **Mean Absolute Percent Error (MAPE):**

This measure evaluates the average error between the values predicted by the MCDM models and the actual or reference values. Equation 1 represents the normalizing formula:

$$MAPE = \frac{1}{n} \sum_{i=1}^n \left| \frac{A_i - P_i}{A_i} \right| \times 100 \tag{1}$$

where A_i represents the real value, P_i is the predicted value, and n is the number of observations, [10].

- **Coefficient of Determination (R^2):**

The R^2 evaluates how well values predicted by MCDM models match actual values. The formula is shown with equation 2:

$$R^2 = 1 - \frac{\sum_{i=1}^n (A_i - P_i)^2}{\sum_{i=1}^n (A_i - \bar{A})^2} \tag{2}$$

where \bar{A} is the average of the real values.

- **Error variance:** The dispersion of errors between expected and actual values is assessed using this metric.

4.2 Validation Results

According to the MCDM model validation results, the error variance is **0.042**, the **R2** is **0.87**, and the

MAPE is **6.5%**. These findings show that the models employed have a low average error and are dependable.

4.3 Sensitivity Analysis

A sensitivity analysis was performed to determine the robustness of the suggested methodology.

The goal of this study was to see how modifications to the criterion weighting, as derived using the Entropy technique, affected the MCDM ranking outcomes.

The sensitivity analysis methodology involved gradually altering criterion weighting by **±10%**.

The final ranks were then recalculated under each weighting adjustment scenario. This method allows us to evaluate the stability of the ranks in the face of weighting changes.

4.3.1 Sensitivity Analysis Results

The results of the sensitivity analysis show that, despite fluctuations in ponderation, the rankings remain globally consistent. The reliability of the proposed methodology is demonstrated by the fact that in **75%** of the scenarios evaluated, the top three ranking possibilities remain unchanged.

5 Conclusion

The textile sector is energy-intensive and complicated, therefore energy efficiency is a top priority, particularly for small and medium-sized firms (SMEs), who account for the vast majority of the market. Despite the availability of several energy-saving technologies and techniques, their implementation is frequently limited due to a lack of knowledge and funds, particularly in SMEs. This essay demonstrates that there are several energy-saving measures that can result in significant savings, ranging from machine modernization to the streamlining of existing routines.

Furthermore, because of their high return on investment, these tactics can benefit even small businesses. To properly use these technologies, textile companies must invest in training and get familiar with optimum energy-saving methods. Cutting-edge Industry 4.0 technologies, such as automation and real-time data processing, provide new potential to boost competitiveness while reducing environmental impact.

In conclusion, there are workable energy efficiency methods that may be implemented at affordable prices, despite the fact that there are still obstacles to overcome. In order for textile mills to achieve significant energy savings and contribute to

a more sustainable and competitive business, there has to be a greater awareness and dissemination of information about these technologies.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

The authors wrote, reviewed and edited the content as needed and verifies that none utilised artificial intelligence (AI) tools were used. The authors take full responsibility for the content of the publication.

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APPENDIX

Table 2. Energy savings, [9]

Cross-cutting technologies and measures in energy efficiency	Electricity savings	Refund
Electricity demand control		
Opportunities for improving energy efficiency in electric motors		
Motors Management Plan		
maintenance	2% - 30% of engine system energy consumption	
High energy efficiency Motors		
Rewinding motors		
Correct motor sizing		
Adjustable speed variators	7% - 60%	< 3
Power factor correction		
Minimize voltage imbalances		
Opportunities for improving energy efficiency in compressed air systems		
Reduction in demand		
Maintenance		
Control		
Reduced leaks (in pipes and equipment)	Up to 20% of compressed air system energy usage	
Electronic Condensate Drains (ECDT)		
Reduction of intake air temperature	Every 3°C reduction will save 1% of compressor energy consumption	< 5
Maximize the allowable pressure dew point of entering the air.		
Compressor optimization based on load		
Correct pipe sizing	Up to 3% of compressed air system energy usage	
Heat recovery	Up to 20 % of compressed air system energy usage	< 1
Variable speed drives (ASD)		
	Up to 15 % of compressed air system energy usage	
Opportunities for improving energy efficiency in pumping systems		
Maintenance	2 to 7% of electricity consumption for pumping	< 1
Control		
Reduction in demand		
	10 to 20 % of electricity consumption for pumping	
More efficient pumps		
	2 % to 10% of electricity consumption for pumping	
Correct pump sizing	15% - 25% of electricity consumption for pumping	< 1
Multiple pumps for varying loads		
	10 % -50% of electricity consumption for pumping	
Wheel cutting (or sheaf shaving)		
	Up to 74% of electricity consumption for pumping	
Variable speed drives (ASD)		
	19% - 60% of electricity consumption for pumping	
Avoiding choke valves		
Correct pipe sizing		
Replacing drive belts	Up to 9% of electricity consumption for pumping	< 0.5
Precision castings, surface coatings, or polishing		
Improved waterproofing		

Opportunities for improving energy efficiency in ventilation systems		
Minimize the pressure		
Control density		
Fan efficiency		
Proper fan sizing		
Variable speed drives (ASD)	15% - 48% of the electricity consumption of the ventilation system	
High-performance belts (toothed belts)	3% of the electricity consumption of the ventilation system	1 - 3
Opportunities for improving energy efficiency in the lighting system		
Lighting control		< 2
Replace T-12 tubes with T-8 tubes	115 MWh/year/1196 light bulbs	26800 for 1196 light bulbs
Replace metal halide (HID) with high-intensity lamps. Fluorescent lamps	50% / bulb	187/ device
Replacing magnetic ballasts with electronic ballasts Ballasts	934 kWh/ballast/year	8/ ballast
Factory lighting optimization (Brightness optimization) in production and out of production	32 - 183 MWh/an	
Optimal use of natural sunlight		
Opportunities for improving energy efficiency in steam systems		
Adaptation of demand		< 2
Boiler allocation control		
Smoke duct closing flaps		
Maintenance	Up to 9% of boiler energy used	< 0.5
Improved insulation	7% - 25% of boiler energy used	
Reduction of combustion gas quantities		
Reduction of excess air		< 1
Flue gas monitoring		< 1
Preheating of boiler feed water using heat from flue gas (economizer)	6% - 9% of boiler energy used	< 2
Heat recovery from boiler blowdowns		< 2
Condensate recovery		1
Combined heat and power (CHP)		
Shut down excess distribution lines.		
Correct pipe sizing		
Insulation related measures		1.1
Checking and controlling steam traps	Up to 9% of boiler energy used	< 0.5
Thermostatic steam traps		
Closing steam traps		< 0.5
Reduction of leaks in distribution lines		< 0.5
Recovery of revalorization steam		
Coal preselection	1,5 GJ/tonne of finished fabric	36 000 / system < 0.5