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Energy-Efficiency Technologies and Comparing the Energy Intensity in the Textile Industry

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Abstract

The textile industry is a complicated manufacturing industry because it is a fragmented and heterogeneous sector dominated by small and medium enterprises (SMEs). Energy is one of the main cost factors in the textile industry. In this study, thirteen textile plants from five major sub-sectors of the textile industry in Iran, i.e. spinning, weaving, wet-processing, worsted fabric manufacturing, and carpet manufacturing, were visited. The energy intensity of each plant was calculated and compared against other plants within the same sub-sector. The results showed the range of energy intensities for plants in each sub-sector. It also showed that energy saving/management efforts should be focused on motor-driven systems in spinning plants, whereas in other textile sub-sectors thermal energy is the dominant type of energy used and should be focused on. For conducting a fair and proper comparison/ benchmarking studies, factors that significantly influence the energy intensity across plants within each textile sub-sector (explanatory variables) are explained. Finally, a list of energy efficiency improvement measures observed during this study are presented.

1. Introduction

Although being an important industry sector with significant energy consumption, there are not many scientific papers published to address the energy issues in the textile industry, especially when compared to the energy-intensive industries. Ozturk (2005) reports on energy use and energy cost in the Turkish textile industry based on conducted surveys. Martinez (2010) analyses the development of energy-efficiency measures in the German and Colombian textile industries, using three alternative indicators to measure energy-efficiency performance between 1998 and 2005. A recent study in Taiwan summarizes the energy savings implemented by 303 firms in Taiwan's textile industry from the on-line energy Declaration System in 2008. It was found that the total implemented energy savings amounted to 1929 terajoules (Hong, et al. 2010). Zabaniotou and Andreou (2010) describe the development of alternative energy in the textile industry by energy recovery from cotton ginning waste. Palanichamy and Sundar Babu (2005) studied energy use in the Indian textile industry and present the energy-efficiency potential availability. Hasanbeigi (2010) report is a comprehensive collection of around 190 sector-specific and cross-cutting energy-efficiency measures and technologies for the textile industry.

This paper aims to contribute to the understanding of energy use in the textile industry by presenting the energy use of textile plants in five major sub-sectors in Iran, i.e. spinning, weaving, wet-processing, worsted fabric manufacturing, and carpet manufacturing. There are not many published papers that

cover the energy intensity of all of the above sub-sectors. The empirical data of this study was collected from Iran's textile industry in 2005. The complementary analysis of energy intensities and ways to improve such analysis presented in this paper was done is 2010.

2. Methodology

Energy intensity analysis of a textile plant and comparing it with other plants and/or benchmarks enables the top management as well as the energy manager of the plant to identify best practices of the plant or other similar plants that can be replicated. Comparison of the energy intensities can be done in various ways and for different purposes, and can be applied at many different scopes. However, there are certain key issues and steps that should be considered while undertaking such comparison. Based on US EPA (2007), the key steps in comparison/benchmarking include:

- Determine the level of comparison/benchmarking: in this study the comparison was conducted at the plant-level.
- Develop metrics: in this study the energy intensity indicator was selected as the metric. The energy intensities in this study are calculated based on the physical output of the plant to better reflect the energy-efficiency. The electricity intensity and fuel intensities are calculated separately.
- Conduct comparisons: This paper compares the energy intensities of plants in each textile sub-sector.
- Track performance over time: This step is necessary for plants to determine if energy performance is improved or worsened over time in order to take the appropriate actions. However, the plant performance monitoring was outside the scope of this study.

Five major textile sub-sectors are studied: 1) Spinning, 2) Weaving, 3) Wet-processing: Pretreatment, dyeing, printing, and finishing of cotton or polyester fabrics or blended fabrics (cotton/polyester, polyester/viscose, etc.), 4) Worsted fabric manufacturing, and 5) Carpet manufacturing. Within this project, more than 20 textile plants from different sub-sectors were visited and walk-through audits were conducted in each one. However, this paper presents the results for only 13 of these plants for which we could get high quality data. For confidentiality reasons, no identifying information of the plants is disclosed in this paper and the plants are identified only with alphabetical letters.

Fuel used in Iran's textile industry is in the forms of fuel oil, gas oil, LPG, and natural gas mostly for steam generation in steam boilers. Electricity is the common power source for machinery, air conditioning and humidification systems, compressed air systems, lighting, office equipment, etc. Spinning, weaving and wet-processing have the highest share of energy consumption in the textile industry worldwide. Spinning plants mostly use electricity and only use fuel for producing steam used in the air conditioning systems in cold seasons. If spinning plants have yarn dyeing section, then the steam is also used in the yarn dyeing process. Similar to the spinning plants, weaving plants also use electricity in electric motor systems and fuel is used for heating purpose in cold seasons. In addition, weaving plants usually have sizing process which uses significant amount of steam for preparing the sizing material and also for drying the yarns after sizing. The main type of energy used in wet-processing plants is the fuel use. This is because of

many high temperature processes that exist is wet-processing plants such as dyeing, printing, finishing, and drying.

Three spinning plants were visited, two of which (plants A and B) were ring spinning and one (plant C) was open-end spinning. Therefore, a comparison between energy consumption in ring and open end spinning, which are the most common cotton-spinning systems in the textile industry, was conducted. Two weaving plants with a production capacity of more than 6000 (ton/year) of cotton, polyester or blended fabrics (cotton/polyester, polyester/viscose, etc.) were visited. Both of these plants have preparation (warping and sizing of warp yarns) and weaving subsections. Three dyeing, printing, and finishing plants which were processing cotton, polyester or blended fabrics (cotton/polyester, polyester/viscose, etc.) were also studied. Two of them (factories F and G) have printing processes, while another one (plant H) does not have a printing process. Furthermore, it should be highlighted that in plants F and G the process of preparation and finishing on the fabric were more complete than those in plant H. Hence, the quality and price of the final products of plant F and G are higher than those of for plant H.

In the worsted fabric manufacturing sector of Iran's textile industry, three plants were visited which are among the largest worsted fabric manufacturing in Iran (plants I, J, K). All these plants were complex. In other words, they all have spinning, weaving, dyeing, and finishing subsections. Also two carpet manufacturing plants (plants L and M) were visited.

During the walk-through audits, which took one or two days per plant, the plant processes and energy utilities were visited. No measurement was conducted during the visits and only existing data for production and energy use (electricity and fuel) were collected. Based on the collected data, the energy intensity of the plants was calculated for the year 2003 (both electricity and fuel intensities) using the following formula:

Energy Intensity (MWh or GJ/unit of product) =
energy use (MWh or GJ) / production (unit of product)

3. Results and discussion

3.1. Spinning plants

Three spinning plants were studied, two of which were ring spinning (plants A, and B) and one was open-end spinning (plant C). All of these plants have short staple spinning systems, which produce cotton yarn, polyester yarn, or blended yarn (cotton/polyester, viscose/polyester, etc.). In all ring spinning plants, part of the production was committed to double ply yarns. Doubling was being done by two-for-one (TFO) machines. The production, energy use, and calculated energy intensities for these three spinning plants are shown in Table 1.

As can be seen from Table 1, in all spinning plants, around 60% - 70% of the final energy is used as electricity in machinery, humidification systems, compressed air systems, and lighting. Fossil fuels are

used for steam generation. The steam is used in the humidification system for heating purposes in cold months.

Table 1. Production, energy use, and energy intensities for spinning plants in 2003

Plant	Annual Production (tonne yarn)	Annual Electricity consumption (kWh)	Annual fuel consumption (GJ)	Electricity Intensity (MWh/tonne yarn)	Fuel Intensity (GJ/tonne yarn)	Total Final Energy Intensity (GJ/tonne yarn)	Total Primary Energy Intensity (GJ/tonne yarn) [a]
Plant A	2003	13,290,450	24,760	6.6	12.4	36.2	84.9
Plant B	8140	38,584,206	57,694	4.7	7.1	24.2	58.9
Plant C	2448	8,860,300	19,808	3.6	8.1	21.1	47.7

[a] In final energy, electricity use is equal to the electricity consumption at the end-use. In primary energy, electricity use at the end-use is converted to the primary energy sources by taking into account the power generation efficiency (average net heat rate of power plants) and transmission and distribution losses.

Table 1 also shows that specific electricity consumption in plant C is less than the other plants. The reason could be that plant C has an open-end spinning system which has a shorter process in comparison with ring spinning systems (plant A and B). In addition, the production capacity of an open-end spinning machine is usually higher than that of a ring spinning machine. Also, because of the fact that in open-end spinning system, the process is shorter with less machinery, the volume of the building which houses the spinning unit requiring air conditioning is smaller. As a result, the load on the air conditioning system will be less and the energy use is lower.

The specific fuel consumption in plant B is less than plant A and C. In addition to the differences in efficiency, this could be because plant B is located in a city which has a hot climate and there is just four cold months, but the other plants are located in cities which have about six cold months. As a result, in plant B, steam is required for heating in a shorter period of time over a year.

3.2 Weaving plants

The two weaving plants studied were producing cotton, polyester or blended fabrics (cotton/polyester, polyester/viscose, etc.) and both of them have preparation (warping and sizing of warp yarns) and weaving subsections. Similar to spinning plants, in weaving plants the electricity us used mostly for machinery, the humidification system, the compressed air system, and lighting. Fuels are used for producing steam which is consumed in sizing machines and also in the humidification system in cold months. The production, energy use, and calculated energy intensities for these two weaving plants are shown in Table 2.

Table 2. Production, energy use, and energy intensities for weaving plants in 2003

Plant	Annual Production (tonne fabric)	Annual Electricity consumption (kWh)	Annual fuel consumption (GJ)	Electricity Intensity (MWh/tonne fabric)	Fuel Intensity (GJ/tonne fabric)	Total Final Energy Intensity (GJ/tonne fabric)	Total Primary Energy Intensity (GJ/tonne fabric)
Plant D	6027	1,329,0450	103,993	2.2	17.3	25.2	41.4
Plant E	6299	7,420,040	67,397	1.2	10.7	14.9	23.6

Table 2 shows that the specific electricity consumption in plant E is less than D. In addition to difference in the energy efficiency in different plants studied, there are several other factors that cause the differences observed in energy intensities. One factor could be that in plant E the weaving machines were of the projectile type, which consumes less electricity compared to that of rapier weaving machines used in plant D, assuming the same production conditions and product characteristics. In addition, it is worth highlighting that although the efficiency of the weaving machines in plant D was higher than that of in plant E, the production in plant E was higher. In plant E, the average width of fabrics produced on weaving machines was greater than that of in plant D. This can cause a reduction in energy intensity since a greater amount of fabric (in kilograms) is produced in the specific number of peaks on these weaving machines. The specific fuel consumption in plant E is also less than D. In addition to higher energy-efficiency in plant E, since there are fewer weaving machines in plant E and the production area is smaller, less steam is required for the plant E air conditioning system for heating during cold months, compared to that of plant D, which experiences a longer winter.

3.3 Wet-processing (pretreatment, dyeing/printing, and finishing) plants

For this textile sub-sector, three plants were visited and studied. The types of fabrics processed in these plants were cotton, polyester or blended fabrics (cotton/polyester, polyester/viscose, etc.). Different kinds of dyestuff and chemical auxiliaries and several types of machines were used in these plants. The dominant type of energy used in wet-processing is fuel, as opposed to electricity. This is because of the existence of many high-temperature processes in this sector which mainly require steam. Table 3 shows the production, energy use, and calculated energy intensities for the three wet-processing plants studied.

Table 3. Production, energy use, and energy intensities for wet-processing plants in 2003

Plant	Annual Production (tonne finished fabric)	Annual Electricity consumption (kWh)	Annual fuel consumption (GJ)	Electricity Intensity (MWh/tonne finished fabric)	Fuel Intensity (GJ/tonne finished fabric)	Total Final Energy Intensity (GJ/tonne finished fabric)	Total Primary Energy Intensity (GJ/tonne finished fabric)
Plant F	3531	8,860,300	396,068	2.5	112.2	121.2	139.6
Plant G	2296	3,462,685	193,132	1.5	84.1	89.5	100.6
Plant H	1200	2,553,000	48,354	2.1	40.3	48.0	63.6

Plant F has the highest electricity intensity and plant G has the lowest (Table 3). In addition to difference in the energy efficiency in different plants studied, there are several other factors that cause the differences observed in energy intensities. Compared to other plants, the machines and equipment in plant G were newer and most of the machine motors were energy-efficient motors and many of them had inverters. However, Plant H had the lowest fuel intensity. As mentioned above, plants F and G include a printing sub-process, while plant H does not have a printing sub-process. In addition, in plants F and G the sub-processes of preparation and finishing are more comprehensive and complete than that of plant H. As a result less thermal energy, which is the main type of energy consumed in wet-processing plants, is required in plant H. In plant F, the average width of fabrics was less than that of in plant G and H. This could result in energy waste in some machines, such as in cylinder dryers.

3.4 Worsted fabric manufacturing plants

In the worsted fabric manufacturing sub-sector three plants were studied. All of these plants were complex; that is, they had spinning, weaving, dyeing, and finishing sub-processes in plant. The worsted fabric typically contains 45% wool fiber and 55% polyester fiber. These two fibers are blended in the spinning process.

The weaving machines in all plants were rapier type. There was a variety of machines in the dyeing and finishing sub-processes of these plants, most using different technology providers. However, generally, the dyeing and finishing machinery in plant “I” was more modern than that of the other plants. Contrarily, the spinning and weaving machinery in plants J and K was newer than in plant I since the plant I owners had reinstalled new machinery for these sections. Table 4 shows the production, energy use, and calculated energy intensities for the three worsted fabric production plants.

Since spinning and weaving are the main electricity consumers in complex worsted fabric production plants, and plants J and K have newer spinning and weaving machines, the electricity intensities of these two plants are lower than that of plant I (Table 4). On the other hand, since in plant I the dyeing and finishing machinery is modern, the fuel intensity of this plant is less than that of in the other two plants. Plant K has the highest fuel intensity since machinery in the dyeing and finishing subsection of this plant is very old compared to the other plants. In addition, the amount of redyeing done in plant K was significantly high, as indicated by the plant’s records.

Table 4. Production, energy use, and energy intensities for studied worsted fabric production plants in 2003

Plant	Annual Production (tonne worsted fabric)	Annual Electricity consumption (kWh)	Annual fuel consumption (GJ)	Electricity Intensity (MWh/tonne worsted fabric)	Fuel Intensity (GJ/tonne worsted fabric)	Total Final Energy Intensity (GJ/tonne worsted fabric)	Total Primary Energy Intensity (GJ/tonne worsted fabric)
Plant I	742	16,904,000	135,995	22.8	183.3	265.3	432.3
Plant J	747	14,265,550	221,663	19.1	296.8	365.5	505.5
Plant K	197	4,052,000	78,780	20.6	400.0	474.1	624.9

3.5 Carpet manufacturing plants

Two carpet manufacturing plants were visited in this study (plants L and M). Plant L has fiber dyeing, spinning, carpet weaving, and carpet finishing sub-sections. Plant M, however, has the same sections except the fiber dyeing. In both plants, the spinning sub-process produced a double ply acrylic yarn with a yarn count of Nm=10/2. In weaving, in addition to the acrylic yarn used as pile in carpet, jute yarn with a yarn count of Nm= 4.8 was used as weft and a blended cotton/polyester yarn (35/65) was used as the warp yarn. Several finishing sub-processes, such as primary control, brushing, shearing, darning, etc. were undertaken. The standard carpet size used in this study for calculating energy intensity is 12 m^2. The production, energy use, and calculated energy intensities for these two carpet plants are shown in Table 5.

Table 5. Production, energy use, and energy intensities for studied carpet production plants in 2003

	Annual Production (12 m^2 carpet)	Annual Electricity consumption (kWh)	Annual fuel consumption (GJ)	Electricity Intensity (MWh/12 m^2 carpet)	Fuel Intensity (GJ/12 m^2 carpet)	Total Final Energy Intensity (GJ/12 m^2 carpet)	Total Primary Energy Intensity (GJ/12 m^2 carpet)
Plant L	31,252	4,918,640	60,065	0.2	1.9	2.5	3.6
Plant M	21,200	3,012,000	20,922	0.1	1.0	1.5	2.5

The energy intensities of plant M, especially the fuel intensity, are lower than that of plant L. This is partly because of the fact that plant M does not have the fiber dyeing process because they purchase dyed fibers externally. Since the dyeing process uses significant amounts of steam, higher fuel intensity in plant L compared to plant M is observed.

4. Explanatory Variables

In comparing the energy intensities of plants, key drivers of energy use should be identified and researchers should consider adjusting or normalizing the comparison metrics, for instance, based on the weather, production levels, or product characteristics that affect energy use, etc. Normalizing data

ensures better comparisons (US EPA, 2008). Within the scope of this study and the limited data available, there were various constraints for complete normalization of the energy intensity of plants calculated within each textile sub-sector. Plants were unwilling to provide detailed information about their product portfolios and energy use because of confidentiality/competitiveness issues in the industry.
We tried to explain some of the explanatory variables mentioned below when analyzing and discussing the energy intensity results given in previous section. We tried to choose plants with similar process steps in each sub-sector, so they could be comparable, but none of the studied plants in each sub-sector were completely identical in terms of process, equipment, capacity utilization, production characteristics, etc. Also, the exclusive type of data collected in this study was the readily-available data in the plant which only characterizes plants in the aggregate; i.e. at the plant level. This limitation limits opportunities for detailed normalization of the energy intensities between non-identical plants. Some of the factors that affect textile plant energy intensity and could be addressed during similar future studies are explained below for each textile sub-sector studied.

Spinning: There are different factors that influence the energy intensity of cotton spinning plants, such as:

- The type of spinning: whether the yarn spinning stage of the process is done on a ring frame, an open-end machine, a compact spinning machine, or otherwise, could influence the energy intensity per tonne of yarn produced. The most common cotton spinning systems are ring spinning and open-end spinning systems. Since open-end spinning machines usually have a higher production capacity and also the whole spinning process is shorter for open-end spinning (because of the omission of roving and combing sub-processes), the energy intensity of open-end spinning is usually lower than that of ring spinning. Therefore, in comparing the energy intensity of spinning plants, it is important to consider the type of spinning being undertaken in each plant. It also worth mentioning that many spinning plants have both ring and open-end spinning machines. Therefore, special care should be given in comparing the energy intensity in such plants.
- Combed or carded yarn: in the production of cotton yarn a combing process is sometimes applied to produce finer yarn. However, this process is not done on all yarns. Since combing is an additional process, it increases energy intensity. Therefore, whether or not the yarn is combed could also be consider in comparison.
- Yarn count: yarn count is the metric that represents the fineness of the yarn (e.g. weight per length). The finer the yarn, the more time it takes on the ring frame or open-end machines (which are the bottle-neck of yarn production). In other words, the production of one tonne of yarn with 30 tex[1] takes more time on the ring frame than that of 20 tex. Hence, the energy intensity of the production of finer yarn is higher. This is an important factor that could be considered when comparing spinning plants, if the data is available.
- Yarn twist: the number of twists per one meter of the yarn also influences energy intensity. The number of twists in the yarn is defined by the final use of the yarn. For instance, yarns used in weaving usually need more twists than yarns used in knitting. The higher the number of twists

[1] Tex is one of the several systems to measure the yarn count (fineness). The tex count represents the weight in grams per 1 kilometer (1000 meters) of yarn. For example, a yarn numbered 20 tex weighs 20 grams per kilometer. The tex number increases with the size of the yarn.

per meter, the higher the time spent on the spinning machine; thus higher energy intensity.

- Type of the fiber: The type of fibers used in spinning (cotton, polyester, viscose, or combination of two of them) also influences energy intensity. Cotton usually needs more cleaning; thus it goes through more cleaning sub-processes in the spinning process. This could slightly increase the energy intensity of cotton yarns compared to that of polyester and viscose fiber yarns.
- The climate: The condition of the air inside the spinning plants should be maintained at a fixed level, which depends on the type of fibers being processed. Therefore, in different seasons cooling and heating is applied in the humidification system of the plant. In areas with more moderate climates, less energy is used for heating and/or cooling. Four-season climates or types of extreme weather may result in the need for more heating and cooling which increases energy intensity. This factor was considered while discussing the results of this paper.
- Yarn finishing processes: Spinning plants commonly have additional processes after spinning such as doubling, yarn singeing, mercerizing, dyeing, etc. The existence of any of these processes will increase the plant's energy use. Special care should be given to this issue while conducting comparison between spinning plants in order to make sure identical processes are benchmarks. Plants usually have only one electricity metering system and one system for measuring fuel use, often reporting a single value of total energy use without separating calculating energy use for each process. This issue was taken into account in this study, as each of the plants was visited in person by the authors and the existence of finishing processes was assessed.

Weaving: Different factors that influence the energy intensity of weaving plants are:

- The type of weaving machine (loom): loom type can significantly influence energy intensity. Therefore, when comparing, the type of loom should be identified. However, it should be noted that some looms can only produce fabrics with certain specifications and not all looms can produce all types of fabrics. We explained the type of looms used in weaving plants surveyed and their effect on the calculated energy intensities above.
- The weight of the fabric: The weight of the fabric (g/m^2) influences the amount of production (in tonnes) and thus has an effect on energy intensity. This factor should be taken into account in the normalization of weaving plant energy intensity.
- The width of the fabric: If the width of the fabric is closer to the optimum width of the weaving machine for which it is designed, energy intensity will be lower than for fabrics of shorter widths, assuming both fabrics have similar weights in g/m^2.
- The sizing process: Some weaving plants do the sizing of the warp yarns onsite while some purchase the sized yarn from outside. Sizing uses significant amounts of both electricity and steam and has an effect on the final energy intensity of the plant.
- The climate: The condition of the air inside the weaving plant should be maintained at a fixed level depending on the type of fibers being processed. Therefore, for the same reasons explained for spinning above, this will influence the energy intensity of weaving plants.

Wet-processing: Wet-processing of fabric comprises various processes and equipment. Different factors can influence the energy intensity of wet-processing plants such as:

- The preparation process: Depending on the type of fabric and the specifications of the final products, some fabric may go through a greater number of preparation processes like washing. This directly influences the energy intensity of the final products.
- The final product: Depending on the specifications of the final products, some fabrics may go through additional finishing processes, such as waterproofing, fireproofing, coating, softening, etc. While such additional processes may increase the value of final products, they also increase energy intensity.
- Existence of printing sub-processes: Some fabric wet-processing plants have both printing and dyeing sub-processes, while some others just have either one or the other.
- Geographic location: The boiling point of water decreases with increases in altitude. Significant amounts of steam are used in wet-processing plants; therefore, the geographic location of the plant can influence energy intensity.

Worsted fabric manufacturing: The worsted fabric manufacturing plants surveyed in this study are all complex plants with spinning, weaving and wet-processing; thus, all the issues mentioned above for the spinning, weaving, and wet-processing sub-processes are applicable to them as well.

Carpet manufacturing: Colored acrylic fibers are used in carpet manufacturing. Some plants have a fiber dyeing sub-process, while some others do not. The existence of a fiber dyeing sub-process significantly influences the energy intensity of the plant.

- In this study the unit of production examined is a 12 m^2 carpet. This is because the 12 m^2 carpet is the most common carpet produced in Iran. However, it should be noted that the specific weight (g/m^2) of carpets this size can vary. This can have an effect on the energy intensity of the product. In Iran, however, most 12m^2 carpets have close specific weights,

Many researchers have compared the energy intensity of textile plants in different sub-sectors of the textile industry together; in a few cases the energy intensity of the textile industry is represented by a single number for the whole sector. Given the wide variety of substrates, processes, machinery and components used, and finishing steps undertaken, this aggregated energy intensity measure and sub-sectoral comparisons are of little or no use. Thus, for the textile industry and any other heterogeneous industry, energy intensity should be calculated for each sub-sector separately, as it is done in this paper, in order to have a better representation of energy use efficiency in each sub-sector and have more accurate comparison.
Also evaluating and acting on comparison/benchmarking results are as important as undertaking the comparison activity. Successful energy intensity comparison/benchmarking also requires monitoring and verification to ensure continuous improvement. This is more relevant for plant engineers and energy managers. Monitoring and evaluation was beyond the scope of this particular study.

5. Energy-efficiency Improvement Opportunities in the Textile Industry

Based on the walk-through audit conducted in the plants by the experts as well as the results of this analysis, a list of energy-efficiency measures was prepared and included in the reports that were

submitted to the plants, so they could consider the implementation of those measures. Below we briefly present the list of some of the important energy-efficiency measures for different textile subsectors which are based on both walk-through audits. The typical energy savings and payback periods given in the table are from Hasanbeigi (2010).

5.1. Potential energy-efficiency measures in spinning plants

Energy efficiency measures that can be applied in spinning plants studied are presented in Table 6.

Table 6. Energy-efficiency measures for spinning plants (Hasanbeigi, 2010)

No.	Energy-efficiency measures	Typical Electricity saving	Typical Payback Period (Year)*
1	Installation of electronic roving end-break stop-motion detectors instead of pneumatic systems	3.2 MWh/year/machine	<1
2	Replacement of lighter spindles in place of conventional spindles in ring frames	23 MWh/year/ring frame	8
3	Optimization of ring diameters with respect to yarn count in ring frames	10% of ring frame energy use	2
4	False ceilings in production area	8 kWh/ year/spindle	1.2
5	Installation of energy-efficient motors in ring frames	6.3 -18.83 MWh/year/motor	2 - 4
6	The use of light weight bobbins in ring frames	10.8 MWh/year/ring frame	<1
7	Installation of a soft starter on motor drives of older ring frames	1 – 5.2 MWh/year/ring frame	2
8	Installation of variable frequency drives on autoconer machine	331.2 MWh/year/plant	<1
9	Replacement of nozzles with energy-efficient mist nozzles in yarn conditioning room	31MWh/year/humidification plant	<1
10	Installation of variable frequency drives (VFD) for washer pump motors in humidification plants	20 MWh/year/humidification plant	<1
11	Installation of VFD on humidification system fan motors for flow control	18 -105 MWh/year/fan	1 - 2
12	Automatic energy-efficient control systems for humidification systems	50 MWh/year/ humidification plant	2 – 3.5

*Wherever the payback period was not provided, but the energy and cost were given, the payback period is calculated assuming the price of electricity of US$75/MWh (US$0.075/kWh).

5.2. Potential energy-efficiency measures in weaving plants

Weaving machines (looms) account for a significant portion of energy consumption in a weaving plant. Humidification, compressor and lighting accounts for the rest of the energy used, depending on the types of the looms and wet insertion techniques (Sivaramakrishnan, et al. 2009). Since a loom is just a machine, there are not many physical retrofits that can be done on existing looms to improve their efficiency. Different loom types differ in their energy intensity (energy use per unit of product). However, for a given type of loom, most of the opportunities for energy-efficiency improvements are related to the way the

loom is used (productivity), auxiliary utilities (humidification, compressed air system, lighting, etc), and the maintenance of the looms.
All the measures mentioned in the previous sections which improve the efficiency of humidification systems used in spinning processes are also to a great extent applicable to weaving plants. In addition to those, the below measures will also improve efficiency in the weaving process:

- Loom utilization should be more than 90%. A 10% drop in utilization of loom machines will increase specific energy consumption by 3-4% (Sivaramakrishnan, et al. 2009).
- The electric motor of the loom can be replaced by an energy-efficient motor.
- The type of weaving machine can significantly influence the energy use per unit of product. Therefore, when buying new looms, the energy-efficiency of the loom should be kept in mind.
- The quality of warp and weft yarn directly influences the productivity and hence efficiency of the weaving process. Therefore, using yarns with higher quality that may have a higher cost will result in less yarn breakage and stoppage in the weaving process, and can eventually be more cost-effective than using cheap, low quality yarns in weaving.

5.3. Potential energy-efficiency measures in wet-processing plants

Energy efficiency measures that can be implemented in wet-processing plants are presented in Table 7. There are also many cross-cutting energy-efficiency measures applicable to the studied textile plants in different energy systems such as electric motors, pumps, fans, and compressed air systems, steam systems, and lighting. For a complete list of energy-efficiency technologies and measures and a brief explanation for each measure please refer to Hasanbeigi (2010). For worsted fabric production plants and carpet manufacturing, some of the measures proposed above were also applicable depending on the production process (spinning, weaving, wet-processing).

Table 7. Energy-efficiency measures for wet-processing plants (Hasanbeigi, 2010)

No.	Energy-efficiency measures	Typical Fuel saving	Typical Electricity saving	Typical Payback Period (Year)*
	Preparatory Process			
1	Combined preparatory treatments in wet processing, such as washing, desizing, and scoring	up to 80% of preparatory treatments energy use		
2	Cold-pad-batch pretreatment	up to 38% of pretreatment fuel use	up to 50% of pretreatment electricity use	
3	Bleach bath recovery systems	US$38,500 -US$118,400 saving		2.1
4	Use of counter-flow current for washing process	41% - 62% of washing energy use		
5	Installing heat recovery equipment for continuous washing machines	5 GJ/tonne fabric		
6	Enzymatic removal of residual hydrogen peroxide after bleaching	2,780 GJ/year/plant		
	Dyeing and Printing Process			
7	Heat insulation of high temperature/ high pressure dyeing machines	210 - 280 GJ/year/plant		3.8 – 4.9
8	Automated preparation and dispensing of chemicals in dyeing plants			1.3 – 7.5
9	Installation of VFD on circulation pumps and color tank stirrers		138 MWh/year/plant	< 1
10	Cooling water recovery in batch dyeing machines (jet, beam, package, hank, jig and winches)	1.6 - 2.1 GJ/tonne fabric		1.3 - 3.6
11	Cold-pad-batch dyeing systems	16.3 GJ/tonne of dyed fabric		1.4 - 3.7
12	Discontinuous dyeing with airflow dyeing machines	up to 60% of machine's fuel use		
13	Use of steam coils instead of direct steam heating in batch dyeing machines (winch and jigger)	4580 GJ/year/plant		
14	Equipment optimization in jet dyeing machines	1.8 - 2.4 kg steam /kg fabric	increased 0.07 - 0.12 kWh/kg fabric	1.4 - 3.1
15	Heat recovery of hot waste water in autoclaves	554 MJ/batch product		
16	Reducing the need for re-processing in dyeing	10% -12% of dyeing fuel use		
17	Reduce rinse water temperature	10% of rinsing energy use		
18	Heat recovery from hot rinse water	1.4 - 7.5 GJ/tonne fabric rinsed		< 1
	Drying and Finishing Process			
19	Introduce mechanical de-watering or contact drying before dryer/stenters	13% - 50% of stenter energy use		
20	Avoid overdrying in dryer/stenters			
21	Close exhaust streams during idling in dryer /stenters			
22	Optimize exhaust humidity in dryer /stenters	20 - 80% of stenter energy use		
23	Install heat recovery equipment in dryer /stenters	30% of stenter energy use		1.5 - 6.6
24	Use of sensors and control systems in dryer /stenters	22% of stenter fuel use	11% of stenter electricity use	1.5 - 6.7

*Wherever the payback period was not provided, but the energy and cost were given, the payback period is calculated assuming the price of electricity of US$75/MWh (US$0.075/kWh).

6. Conclusion

The results showed the range of energy intensities for plants in each sub-sector. It also showed that energy saving/management efforts should be focused on motor-driven systems in spinning plants, whereas in other textile sub-sectors thermal energy is the dominant type of energy used and should be focused on. For conducting a fair and proper comparison/ benchmarking studies, factors that significantly influence the energy intensity across plants within each textile sub-sector (explanatory variables) should be taken into account or at least acknowledged. The data collection for the plant level energy intensity with explanatory variable taken into account, process-level energy intensity, or equipment-level energy intensity is difficult. Finally, a list of energy efficiency improvement measures observed during this study are presented.

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