Energy Consumption Characterization based on a Self-analysis Tool: A Case Study in Yarn Manufacturing

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Abstract: Even if energy efficiency represents a crucial issue for the sustainability of the manufacturing industry, the companies need to be encouraged in investing their resources for this goal. One of the means to facilitate this effort is the comparison of the energy performances with similar factories. Nevertheless, since the enterprises are very heterogeneous, these performance values have, even within a specified manufacturing sector, a high variability and therefore risk not to be representative. The dispersion of these data has to be decisively decreased. This goal is pursued here by means of an energy consumption characterization model based on: 1. a self-analysis software tool collecting energy consumption data in a simple and homogeneous way; 2. the clustering of the factories; 3. the separation of the auxiliary energy uses from the production process energy consumption. The method is here applied to textile industry with a focus on the electrical consumption in yarn factories. The outcomes show a correlation with some production variables, such as the raw materials, and allow to reduce the relative errors of the energy performances of different factories from about 80% to about 25-40%. In this way, energy reference indicators can be built in an acceptable and representative way.

1 INTRODUCTION

Energy efficiency has become a crucial issue for the manufacturing industry because of the need of reducing greenhouse and pollutant emissions, of optimizing fuel resources and of increasing economic market competitiveness.

In this paper the textile industry, and in particular the yarn manufacturing, is chosen as a case study for an energy consumption characterization, and the approach which will be outlined here can be applied also to other manufacturing sectors.

In 2015 textile industry in Europe counted 61,000 companies and produced a turnover of around 79,000 million € with an energy cost of about 1,900 million €. The energy cost contribution was higher than the average energy contribution cost of manufacturing sector (EUROSTAT, 2015).

For yarn manufacturing the incidence of the energy costs can vary a lot, depending on many variables, such as the kind of raw materials, the involved processes and labor costs. According to different countries and for 20 tex carded open-end rotor cotton yarn, the share in energy cost represents the 5-18% of the total mill costs (Kaplan, 2010; Alkaya, 2014) and 10-25% for ring and rotor spinning (ITMF, 2014).

In 2016, China, European Union, India and the U.S. were the four largest textile importers and exporters in the world. The EU textile sector represented 23% of the world textile exports (WTO, 2017). In China and in the U.S., the contribution of the textile industry sector to the national final energy use in manufacturing is respectively of the 4% and of the 2% (Hasanbeigi, 2012a). Even if the textile industry is not a very high energy-intensive industry, it involves a large number of plants, consuming together a significant amount of energy.

The purpose of improving energy efficiency in textile industry is a common declared governmental strategy for many regions, such as

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Europe (Scheffer, 2015), Turkey (Alkaya, 2014) and Taiwan (Hong, 2010). The Best available techniques REFerence document (BREFs), prepared by the European IPPC Bureau, describes how to implement the best available techniques to use natural resources in an efficient way and to minimize pollution emissions (IPPC, 2003).

Notwithstanding these government goals and the fact that the payback time is often less than few years, the companies, especially SMEs, are not usually prone to invest time and relevant resources to face a comprehensive energy consumption assessment and to implement the adequate measures.

A dissemination campaign of the several energy saving opportunities can help to overcome the limited information and to make aware of the possible benefits of these measures. Another way to promote and facilitate investments in energy efficiency measures is to provide some reference performance indicators for the energy consumptions of the production processes. This would represent a fast way, even if of preliminary nature, for the factory to understand whether its energy consumptions are efficient or not. Comparisons and benchmarks for the energy consumption of a plant can be based on the past performance of the same plant or on other plants' performance (or average performance) of the same plant group or more general plant groups. Another possibility is the comparison with the performance of "best practice" plants of the same group or performance of "best technologies" in the industry (Hasanbeigi, 2012b). Unfortunately, even factories of the same group are heterogeneous and differ greatly from each other because of different processes involved, different machine setting and kinds of products and different machines and components (Hasanbeigi, 2012a). Even within the same textile sub-sectors, such as yarn manufacturing, fabric manufacturing and finishing, a similar fragmentation occurs.

Moreover, the main available references (e.g. data from EUROSTAT (2015)) are few and too general to be meaningful for all the different kind of companies of the textile sector. In literature benchmarking, no homogeneous description of the plant characteristics and of the implemented processes exists (because of confidentiality issues, besides being a time-consuming activity). Therefore the problem of energy performance comparison, of energy and economical characterization is still unsolved because of the great variability of the production processes.

On the other hand, more accurate estimations of the energy consumption of a textile mill can be provided using more precise equations but referring only to very specific production phases, machines and setting parameters, such as yarn counts and twists. This approach is followed for example by Koç (2007), but it needs a huge amount of time and detailed data, such as the yarn properties, the power and number of the machines, the load factors, the efficiencies and the number and type of processes.

This paper proposes an energy consumption characterization model which allows, by means of self-analyses, to obtain approximate reference values for the comparison. The data for the construction of the model were collected through a set of software tools, named SET Tool, developed within three European projects (ARTISAN, SESEC and SET), which were focused on the Textile and Clothing sector (Branchetti, 2016). Furthermore, an European informative campaign, named Energy Made to Measure (EM2M) (EM2M, 2016), led by the European industry association (EURATEX), has allowed, by means of these software tools, to retrieve many information data from the factories and thus to build a quite large database.

The collected data have been clustered according to the kind of production and the used raw materials. Then, the data have been elaborated using regression analysis methodologies and indicators, such as the Specific Energy Consumption (SEC), which represents the total energy consumption of the whole mill for unit of product (kWh/kg). Here we refer to the "electrical SEC" and "thermal SEC" when representing electrical and thermal energy consumption respectively. The present paper focuses on part of the textile production chain, in particular on the whole yarn manufacturing processes.

The main goals of this paper are:

- to make available to the public literature some energy consumption indicators of the textile industry, as collected by the SET tools, respecting industrial data confidentiality;
- to decrease the range of variability of the SEC for yarn production mills, without taking into account production details; in this way a textile factory can more easily compare its energy consumption with reference values;
- to validate a general approach to compare energy performances in manufacturing industry avoiding detailed, time-consuming and demanding measurement campaigns.

In section 2, energy consumption in yarn manufacturing is discussed, together with a literature review of this issue and of the SEC values. In section 3, the SET Tool and its database are presented along with the used indicators. After examining the relationship between energy and production, the main results are presented in section 4 and discussed in section 5.

2 ENERGY CONSUMPTION IN YARN MANUFACTURING

The textile industry is a complex manufacturing industry because it represents a fragmented and heterogeneous sector, dominated by Small and Medium Enterprises (SMEs) (Hasanbeigi, 2012a). The textile production process is composed of many and different production phases and sub-phases, hierarchically identifiable. Starting from the NACE rev. 2 classification, three main kinds of production can be highlighted:

- yarn production;
- fabric production;
- finishing (of yarn and fabric).

Even if yarn production is made up of various processes, which can be in sequence or alternative, it is possible to define some main production phases, as depicted in Figure 1: opening and preparation of the raw materials (such as cotton and wool), carding, combing, drawing, spinning, winding, rowing, steaming, etc. The dyeing and other finishing processes are not included here in the “yarn production” category. A factory can implement many of these phases or only just one. Moreover, it is possible that these phases occur at different facilities of the same company.

In yarn production most of the energy consumption is due to spinning processes. In case of middle count, carded, ring yarn, the spinning and winding processes represent about 55-80% of the energy consumption per kg of single yarn (Koç, 2007). The spinning systems can be classified according to different technologies into ring spinning, compact spinning, rotor spinning, air-jet spinning and other spinning machines, which are characterized by different energy consumption behaviour. On the other hand, the scientific literature on the energy consumption is not systematic, often outdated and not well documented (Van der Velden, 2014).

Comprehensive studies for a specific textile mill, facing energy consumptions, water consumptions, waste and pollutant generations are reported in Ozturk (2015). Potential energy reduction applying the Best Available Technologies list (BAT) are evaluated there as about 10-30%, with a total potential reduction up to 70% with a payback period up to 4 years (by means of energy monitoring and control, insulations, heat recovery, substitution of electric motors) (IPPC, 2003).

In Hasanbeigi (2012b), the energy consumption of 13 textile plants in Iran have been analyzed and audited, regarding 5 different sub-sectors (spinning, weaving, wet-processing, worsted fabric manufacturing and carpet manufacturing). Therefore there are only 2 or 3 plants in this study in each manufacturing sub-sector, for each of which the energy intensity has been analyzed and then a range of energy consumption has been estimated. Hence, benchmark values for other mills in the same sub-sector are attempted, even if the indicators are deduced from a very limited number of factories. Moreover, the highest share of energy consumption in the textile industry worldwide turns out to be due to spinning, weaving, and wet-processing.

In Lin (2016) Chinese regional differences in the total energy efficiency of the textile industries are analyzed for the period 2000-2012. There, the technology gap is taken as the most important parameter to explain the disparity in energy efficiency in eastern, central and western regions. Considering the distance from the frontier technology, a huge energy saving potential is highlighted for the Chinese textile sector.

Other studies focused their investigations on the whole life cycle of the textile industry using the LCA (Life Cycle Assessment) approach (Steinberger, 2009; Zamani, 2014; Van der Velden, 2014). In these studies the complete chain is taken into account, from the cultivation up to the production, textile use, dress washing and even ironing. The approach is comprehensive, but, on the other hand, only a rough estimation of the production energy consumption is used and a discussion of its high spread is missing.

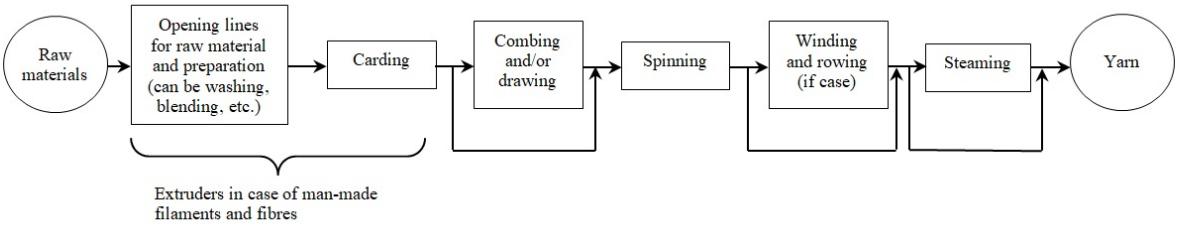

Figure 1: Typical yarn processes.

Table 1: Electrical and thermal energy consumption for yarn production mills according to the analyzed literature.

Description	Electrical energy consumption [kWh/kg]	Thermal energy consumption [MJ/kg]	Reference
Spinning (1972)	5.4		(Kim, 1983)
Spinning (1980)	4.9		(Kim, 1983)
Range for spinning mills	2.7 – 4	1.1 - 4.7	(Tarakçıoğlu, 1984)
Range for textile mills	0.5 - 7.5	11 - 65	(Kumar, 1999) (UNIDO, 2010)
Range of spinning plants	0.55 - 7.3	0.14 - 0.73	(Visvanathan, 2000)
Ring yarn (combed) 20 tex	3.5 - 3.6		(ITMF, 2003)
	1.8 - 5.1		(Dahllöf, 2004)
Cotton spinning (1997)	5.1		(Dahllöf, 2004)
-	11.6		(Ellebæk Larsen, 2007)
Spinning mill (mix ring and open-end, cotton)	3.2 - 3.8		(Kaplan and Koç, 2010)
Open-end spinning mill (calculated, 20 tex)	3.0		(Kaplan , 2010)
Specific spinning plant	3.2 - 3.5		(Palamutcu, 2010)
Spinning plant	3.2 - 3.5		(EMS)
Ring spinning mills	6.6, 4.7	12.4, 7.1	(Hasanbeigi, 2012b)
Open-end Spinning mills	3.6	8.1	(Hasanbeigi, 2012b)
SimaPro 7.2	5.1		(Van der Velden, 2014)
SimaPro 7.2	3.4		(Van der Velden, 2014)

Table 1 reviews and summarizes the data found in the abovementioned references and in other literature. The data are presented in chronological order and reported in Figure 2. The bars show the ranges of values declared by the respective references. Figure 2 confirms the wide distribution of the data, but also a general consistency among them. The ranges of the data is 0.5-11.6 kWh/kg and the average turns out to be 4.5 kWh/kg. Reference Van der Velden (2014) claims that the wide range of the literature data is mainly due to the mixture of data coming from very different textile product characteristics, the most relevant of which is the yarn count.

Anyhow, as abovementioned, the range of the data is too high to be useful for benchmarking purposes. As shown in Figure 2, SEC in yarn manufacturing can vary by a factor of 20. Values of SEC, as a matter of fact, depend on many factors and choices, such as the raw materials characteristics (Hasanbeigi, 2012b), type and number of processes taken into account, type of spinning system, yarn count (Van der Velden, 2014; Koç, 2007), yarn twist (Hasanbeigi, 2012b), energy efficiency of the machines and machine time utilization (the workload), geographical location (Hasanbeigi, 2012b), production capacity (Palamutcu, 2010). Moreover, the technology evolution has to be taken into account as well, because it drives a decrease of the SEC with time. This issue has been investigated for Germany and Colombia from 1998 to 2005 in Pardo Martínez (2010).

Even the detailed energy consumption analysis for a specific mill is not easy. Direct measurements in 5 plants in Palamutcu (2010) show discrepancies between estimated and actual energy data of the order of 10-30% due to the variety of different processes, the efficient use of the equipment, processes steps, the discontinuity of machine use by cause of maintenance periods.

From this description, it is clear that an unique reference number representing the energy consumption of the whole textile industry is poorly representative for a specific mill, because the textile factories have very different features. On the other hand, this paper does not take into account all these variables, because this would have required a deep analysis of the machines and costs from the textile plants. Rather, the approach proposed here is to consider only few more significant variables, such as the type of production process and the main raw materials.

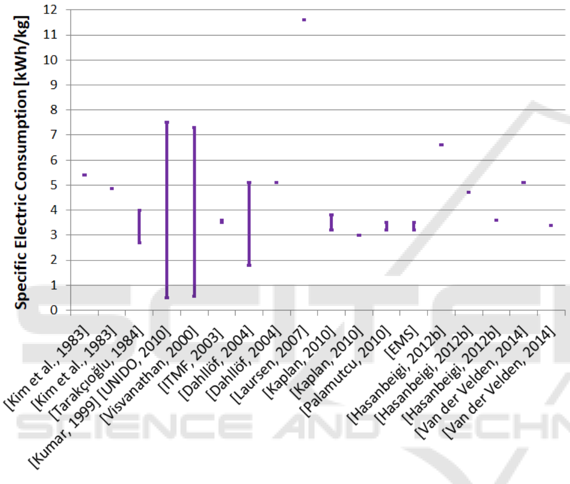

Figure 2: Range of specific electrical energy consumptions (kWh/kg) for yarn mills from the analyzed literature reported in Table 1.

3 METHODS

The proposed methodology is based on the so-called SET Tool, that is a self-analysis standalone tool which provides feedback on energy efficiency measures and energy indices to the textile mills interested in investigating this issue. Enterprises are encouraged by the tool to provide information on: the yearly and monthly production amount, the electrical and thermal consumptions of the mill, the number and the type of processes involved, the turnover, the number of employees, the main used raw materials, the product market segment and the market segment application (clothing, home textile, technical textile, etc.).

The SET Tool was designed together with a web-based application, named SET Web, which is able to retrieve and filter data, to check their faithfulness and to calculate customized energy benchmarks. Enterprises can access SET Web and its services, obtaining performances comparison with energy benchmarks, by anonymously sending their data through the SET Tool. As a matter of fact, all these data are provided by the textile factories themselves and are automatically recorded and organized to build up a centralized and growing SET database. With respect to other benchmarking methodologies (Andersson, 2018), the energy benchmarks obtained by the SET Tool are built dynamically through company self-profiling. Therefore, the companies themselves contribute to improve the quality of the benchmark.

3.1 The Factory Database

At the end of 2017, the factory database was composed of 204 datasets, which were provided by 136 companies in relation to 140 factories. Pruning the data referring to the same production but to different years and those being inconsistent or not complete, 123 datasets have been selected, regarding 4 main areas: yarn production, fabric production, finishing processes and factories involving a combination of these productions (yarn and finishing of yarn, fabric and finishing of fabric or the overall production processes). Table 2 shows characteristics and consumption indices of the mills, which have uploaded the data. The data mainly refer to the years 2014-2015.

From the SET datasets it is possible to provide a quite general view of the energy consumption in yarn production, fabric production and finishing in Europe: the numbers of the textile factories which have been collected with the SET Tool are about 25-40 for every sector. Even if some outliers and incomplete datasets have been excluded, the range and the spread of the total energy consumption values are still very high (0.09 – 16.5 kgoe/kg) because different kinds of textile factories have been collected.

3.2 Electrical and Thermal Energy

In textile industry, both electrical energy and thermal energy are used. The former one is used mainly for operating machines (e.g. spinning, weaving and knitting) and facilities such as air compressors, air conditioning and lathing, while the latter one mainly for heating and production processes such as fixation of yarns, steam for autoclaves and hot water for dyeing.

According to the different types of processes and products, thermal energy or electrical energy can prevail.

In UNIDO (2010) the electrical consumption rate in the total consumed energy for individual textile production stages are reported to be 93% for spinning, 85% for weaving, 43% for wet processing and 65% for clothing manufacturing. The rest of the energy is provided as thermal energy by other energy fuels (natural gas, coal, etc.). According to three spinning plants analyzed in (Hasanbeigi, 2012b), 60-70% of the used energy is electricity (for machinery, humidification systems, compressed air systems and lighting). The spinning step accounts for 56% of total energy use in the yarn manufacturing process (Hong, 2010).

Table 2: Characteristics of the SET datasets with min. and max. values. Primary energy (*) is expressed by kilogram of oil equivalent [kgoe] using a conversion factor of 0.000215 toe/kWhe (Table 4 of Commission decision 2007/589/CE and Annex II of directive 2006/32/CE).

	Yarn	Fabric	Finishing	Yarn+Finishing Fabric+Finishing Yarn+Fabric+Finishing
Factories	26	49	29	36
n. of mills consistent and complete	21	44	27	31
Date for reference year	2013 - 2015	2013 - 2015	2012 - 2015	2013 - 2015
European countries involved	BE, CZ, HU, IT, PT, RO	BE, BG, CZ, DE, HU, PT, RO	CZ, DE, FR, HU, IT, PT	BE, DE, HR, HU, IT, CZ, LT, PT, RO
Number of employees	5 - 535	3 - 410	6 - 200	15 - 1000
Turnover [Millions of €]	0.15 - 90	0.10 - 35	0.19 - 24	0.71 - 116
Product market segment	From low target market to luxury market	From low target market to luxury market	From medium target market to luxury market	From medium target market to luxury market
Market segment application	Clothing, Home textile, Technical textile, Protective textile	Clothing, Home textile, Technical textile, Underwear	Clothing, Home textile, Technical textile, Underwear, Protective textile, Other	Clothing, Home textile, Technical textile, Underwear, Protective textile
Main raw materials used	Cotton, Wool, Acrylic, Polyamide, Polypropylene, Linen, Other natural fibres	Cotton, Wool, Acrylic, Polyester, Polyamide, Polypropylene, Linen, Other natural fibres	mainly Cotton, but also Polypropylene, Polyester, Polyamide, Silk, Wool and Other synthetic fibres	Cotton, Wool, Polyester, Polyamide, Acrylic, Linen, Acetate, Other natural fibres, Other
Electrical energy consumption [kWhe/kg]	0.44 – 14.55	0.49 – 25.14	0.49 – 32.98	1.11 – 17.87
Thermal energy consumption [kWhth/kg]	0.01 – 20.30	0.00 – 44.40	2.43 – 109.69	2.39 – 54.24
Total energy consumption [kgoe/kg]*	0.088 – 3.89	0.11 – 9.22	0.560 – 16.52	0.61 – 7.35
% Electrical energy	from 52% up to 100%, with average of 85%	from 15% up to 100%, with average of 73%	from 13% up to 76%, with average of 28%	from 21% up to 80%, with average of 47%
% Thermal energy	from 0% up to 48%, with average of 15%	from 0% up to 85%, with average of 27%	from 24% up to 87%, with average of 72%	from 20% up to 79%, with average of 53%
Annual product amount [tonnes/year]	30 - 32781	5 - 1767	60 - 4800	55 - 15165

Table 3: Electrical consumption rate with respect to the sum of electrical and thermal consumption for each type of production in textile mills.

	Type of production	Literature	SET database
Distinct textile areas	Spinning (yarn production)	93% (UNIDO, 2010) 60-70% (Hasanbeigi, 2012b) 56% (Hong, 2010)	85% (average of 21 mills)
	Weaving (fabric production)	85% (UNIDO, 2010)	73% (average of 44 mills)
	Wet processing (finishing)	43% (UNIDO, 2010)	28% (average of 27 mills)
Composite textile areas	Yarn production and finishing	-	56% (average of 4 mills)
	Fabric production and finishing	-	42% (average of 22 mills)
	Yarn, fabric and finishing	-	61% (average of 5 mills)

In wet textile processing thermal energy prevails, because of high temperature processes (Hong, 2010) and this is confirmed by the SET database analysis. Table 3 shows some data found in literature compared to data of the present paper (obtained by the SET database). From the SET datasets (Table 2), the electrical energy consumption prevails on thermal energy consumption for both yarn and fabric production with an average of 85% and 73% respectively.

On the other hand, the thermal energy consumption prevails in finishing factories (electrical energy consumption has an average value of 28%). The energy consumption in factories of composite textile areas depends on the different mix of production processes and thus the splitting of energy consumptions between electrical and thermal appears more balanced with respect to distinct textile areas, showing an average of electrical energy consumption ranging from 42% to 61% (Table 3).

3.3 Relationship between Energy and Production

The SEC is the main indicator to express the energy efficiency of a factory and it represents the energy consumption of the whole factory per unit of product (kWh/kg).

In order to obtain further information about the energy management of the companies, the Incremental Energy Consumption (IEC) is here introduced, representing the energy consumption to produce an additional unit of product (kWh/kg). This indicator is obtained by investigating the relationship between the monthly production and the monthly energy consumption, since the energy consumption is expected to be related to the production (Palamutcu, 2010; Branchetti, 2016).

With a regression analysis method, the energy consumption is estimated as:

$$y = m \cdot x + q \quad (1)$$

Where, y denotes the whole energy consumption [kWh], m is the energy consumption to produce each additional unit of product [kWh/kg], x is the production amount [kg], q is the consumption when the production is zero [kWh].

The model parameters (the slope m and the interception q of the best fit line) were estimated for all the available factories of SET database correlating the monthly production (independent variable) with the electrical and thermal energy consumptions (dependent variables). In this way, m represents the IEC and it can be calculated both for the electrical and thermal energy.

The strength of the relationship between production and energy consumptions (respectively, electrical and thermal) for the SET database factories has been checked by means of the correlation coefficient R^2.

When R^2 is close to 1, then the model fits the data with good agreement and the energy consumption appears strongly correlated to the production. In these cases, it is possible to evaluate the “base energy consumption”, which is the portion (percentage) of the total energy not related to the production (Branchetti, 2016). The “base energy consumption” represents the energy auxiliary uses (such as lighting, air conditioning, heating and ventilation) and contributes to the increase of the SEC, whereas it does not affect the IEC indicator of the company.

On the other hand, in factories with a low R^2, and then with a low correlation between energy consumption and production, it is not possible to evaluate the “base energy consumption” and, in these cases, the factories may have not an adequate management of the energy consumption or the production might be composed of a wide mix of different products and raw materials.

4 RESULTS

In the regression analysis for the SET datasets, the values of the model parameters have been accepted only when $R^2>0.5$. Focusing on the 21 textile factories for yarn production (Table 2), the linear regression analysis shows that the electrical R^2 is greater than 0.5 for 13 factories, whereas the thermal R^2 is greater than 0.5 only for 1 factory.

The subsequent analysis is then focused on electrical energy only, because of the prevalence of electricity uses with respect to thermal energy in yarn manufacturing and of the better correlation of electricity with production.

The electrical SEC of the 13 factories ranges from 1.4 to 14.5 kWh$_e$/kg with an average of 5.6 kWh$_e$/kg, a standard deviation (std) of 4.6 kWh$_e$/kg and a relative error (std/average) of 83% (Table 4). On the other hand, the electrical IEC of these factories ranges from 1.1 to 7.9 kWh$_e$/kg and has an average of 3.5 kWh$_e$/kg with a standard deviation (std) of 2.2 kWh$_e$/kg and a relative error of 64%.

Table 4: Electrical SEC and IEC for factories with $R^2>0.5$.

	Average [kWh$_e$/kg]	std	Relative error
Electrical SEC	5.6	± 4.6	83%
Electrical IEC	3.5	± 2.2	64%

Clustering the electrical SEC based on the kind of raw materials (Table 5 and Figure 3), the factories producing wool yarn show an electrical SEC ranging between 6 to 14 kWh$_e$/kg, which is higher than the electrical SEC for factories producing yarn starting from raw materials composed mainly of cotton or “other materials” (i.e. linen, polyamide, acrylic and polypropylene). The latter, as a matter of fact, ranges between 2 and 4 kWh$_e$/kg.

Table 5: Electrical SEC and related std clustered by the kind of raw materials for factories with $R^2>0.5$.

Electrical SEC	Average [kWh$_e$/kg]	std	Relative error
WOOL	10.4	± 4.0	39%
COTTON	2.4	± 0.6	26%
OTHER	2.7	± 1.0	37%

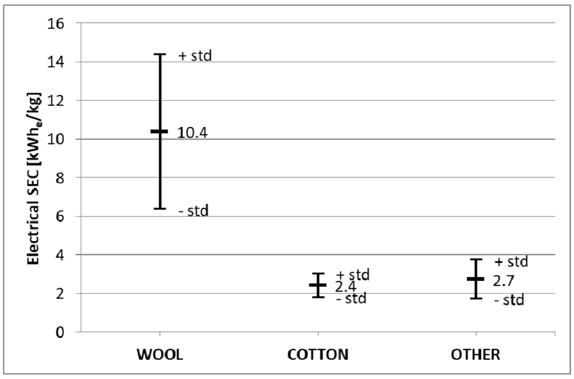

Figure 3: Electrical SEC clustered by the kind of raw material for factories with $R^2>0.5$.

Similarly results are obtained for electrical IEC (Table 6 and Figure 4). The factories producing wool yarn show an electrical IEC ranging between 4 to 8 kWh$_e$/kg, higher than the other clusters, which ranges between 1 and 3 kWh$_e$/kg.

Table 6: Electrical IEC and related std clustered by the kind of raw materials for factories with $R^2>0.5$.

Electrical IEC	Average [kWh$_e$/kg]	std	Relative error
WOOL	5.8	± 1.7	29%
COTTON	1.8	± 0.7	38%
OTHER	2.2	± 0.8	37%

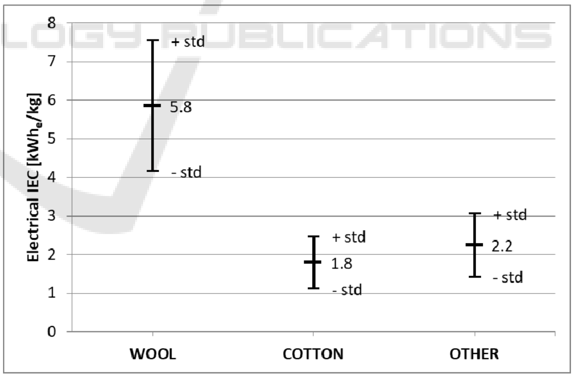

Figure 4: Electrical IEC clustered by the kind of raw materials for factories with $R^2>0.5$.

5 DISCUSSION OF THE RESULTS

The dataset extracted from the SET database for yarn manufacturing confirms the prevalence of electrical energy consumption with respect to the thermal consumption and shows an electrical SEC ranging from 1.4 to 14.5 kWh/kg with an average of 5.6 kWh/kg and a high relative error of about 83%.

This range of values and its spread are compatible with those found in literature (Figure 2) and are due to many factors and choices already described in section 2.2.

The regression analysis method applied to the monthly data of each yarn manufacturing dataset allows to calculate the electrical consumption per each additional produced unit and the base electrical energy consumption (auxiliary energy uses). The latter ranges from 6.2% to 50.3%, with an average of 28%, and it is compatible with the energy consumption values found in literature (Kaplan, 2010). Concerning the electrical energy consumption per each additional unit of product (electrical IEC), the outcome shows that it ranges from 1.1 to 7.9 kWh/kg with an average value of 3.5 kWh/kg and with a lower relative error (64%) with respect to the electrical SEC. The reason is that the auxiliary energy uses in SEC added a further variability in the electrical consumptions.

Clustering the data by raw materials, we have found that the production of yarn based on wool is more energy consuming than the production of yarn starting from cotton or other fibers. This result has been verified for both electrical SEC and electrical IEC indicator. On the contrary, the clustering based on market segment application of products (e.g. clothing, home textile, etc.) or product market segment (luxury, top, medium and low), does not show satisfactory results.

The thermal electrical consumption is less significant in yarn manufacturing, because in average it contributes to about the 15% of the total energy consumption of the factory (see table 2). Moreover, it is not strictly related to yarn production (only one yarn manufacturing mill of the SET database shows a correlation coefficient $R^2>0.5$).

6 CONCLUSIONS

In order to provide a fast and easy method to the factories to preliminary evaluate their own energy consumptions, a reference indicator would be useful for a comparison. This would deliver a fair trade-off between too general or too specific approaches and between too naïve or too demanding methodologies.

Unfortunately the factories have very different features: the textile production chains, even in their sub-sectors segments, combine very heterogeneous and fragmented processes and type of products. Consequently, the energy indicators appear highly variable and poorly representative.

The difficulties were tackled using a factory self-analysis approach which has allowed to retrieve and analyze wide and detailed sets of data. The SET database, obtained by the SET tools, has been presented in this paper and the yarn manufacturing data have been investigated with the final goal of obtaining valuable references for energy consumptions.

The SET database counts 204 sets of data regarding 140 factories and 4 main textile areas: yarn production, fabric production, finishing processes and a combination of them.

The results for yarn manufacturing are complementary and consistent with respect to the available literature and public data. They confirm a high variability of SEC values within the textile sector, but also a correlation with some production variables, such as processes and raw materials. The outcomes enrich the available data for the textile industry and in particular for yarn manufacturing.

Clustering the datasets on the base of raw materials allows to decrease the relative error from 83% to 25-40%

The separation of the auxiliary energy uses from the production process energy consumption allows the comparison of different energy contributions among similar factories. The factories producing wool yarn show electrical energy consumption per each additional unit of product ranging from 4 to 8 kWhe/kg, while it ranges from 1 to 3 kWhe/kg for factories producing yarn composed mainly of cotton fibres or “other materials” (i.e. linen, polyamide, acrylic and polypropylene).

The self-analysis approach allows to create a self-growing dataset with indicators which are supposed to become more and more representative along with increasing factory involvement. From this perspective, the SET database is meant to be a starting point to build up comprehensive and consistent models to depict energy consumptions for textile industry. Moreover, the approach followed in this paper can be implemented also in other manufacturing sectors, even if clustering choices and their usefulness depend on the particular chosen sector and have to be verified case-by-case.

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The results of this paper cannot be intended as official reference values to be used for applications of national subsidies for energy efficiency measures.

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