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Environmental analysis of a cotton yarn supply chain

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A B S T R A C T

This study compares the environmental impacts related to the production of cotton yarn from cultivation to washing and drying, when cotton is supplied by four companies located in four different countries (Egypt, China, India and the USA). Interesting results have been obtained from cultivation scenarios where the productivity influences the value of the environmental impact associated to each country. The highest greenhouse effect is produced by the Indian company, with 0.89 kg of CO_2 equivalent (per 1 kg of cotton).

Fuel consumption and Ammonium nitrate are the first items of greenhouse effect in all companies because of their extensive use and the lack of rotation with other unprofitable crops. In Chinese and Egyptian companies the irrigation sources are severely threatened and it is necessary to switch from a flood irrigation to a drip irrigation system.

The production phase of cotton yarn provides an impact equal to 2.81 CO_2 kg-equivalent. The most critical impacts of cotton yarn production are due to Dyeing (1.24 CO_2 kg-eq.) and Spinning (0.64 CO_2 kg-eq.) phases and they are essentially connected to reactive reagents and pigments, electrical and thermal energy. Regarding thermal energy consumptions some improvements in dyeing plants (recover cooling water, return steam condensate to boilers or reuse different process waters) may allow the company to decrease in CO_2 emission by 41.7%. Moreover a reduction in CO_2 emission by 34.6% can be achieved in the spinning phase using an optimized suction tube in conjunction with adjustable inverter control.

1. Introduction

The growing interest in “sustainable development” has led many companies to examine the ways in which they deal with environmental issues (Glazebrook et al., 2000). Different tools, concepts and ideas to support these objectives have been developed in the last 20–30 years. In this work a Life Cycle Assessment (LCA) technique has been used to quantify the environmental impact connected to the cotton yarn supply chain (SC).

Cotton is an important economic fibre, representing 40 percent of the total fibres consumed in the textile industry in 2004 (Wakelyn et al., 2007). Grown across the world, cotton flourishes in areas that are traditionally too dry for other crops. On average about 2.5–3.0 tons of cotton stalks are generated for every hectare of cotton cultivation. The top four producers (China, India, the U.S. and Pakistan) accounted for almost 80% of the world production in 2006 (Altin et al., 2000). Every production system is characterised by a very different extension of the land intended for planting, cultivation, irrigation, chemicals used and the volume of crops. In order to develop a sustainable supply chain of cotton yarn different scenarios in cotton cultivation and production must be compared. The environmental impact associated with cotton production is increasingly in the spotlight. However, data on the sustainability of cotton production are scanty and not widely available. Despite the general lack of accurate data, it is concluded that water and pesticide use cause the most significant environmental problems in cotton systems. The use of pesticides in several developing countries is of particular concern. Cotton cultivation has been estimated to consume 11% of the world's pesticides while it is grown on only 2.4% of the world's arable land. Insecticides used in cotton cultivation represent 25% of the global consumption (Scheffer, 2005). In developing countries it is estimated that approximately 50% of all pesticides are applied in cotton cultivation. In addition, pesticide use and storage are often badly managed. Moreover, cotton requires large amounts of water both for cultivation and processing. Irrigation is used in areas where normal precipitation quantities do not match the requirements for the crop being cultivated. 53% of cotton fields worldwide are irrigated and because irrigated cotton generally has higher yields per unit of area, this translates to 73% of all

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cotton production (Clay, 2004). The most commonly used irrigation system for cotton cultivation is the flood-or-furrow irrigation system, which although easiest to install, has the lowest water efficiency, 40% at most. In the twelve leading cotton producing countries an estimated 12–36% of the area under cotton cultivation is affected to some degree by salinisation (Stockle, 2001). Soil salinisation occurs when evapo-transpiration exceeds rainfall and is as such a threat for irrigated areas in particular. Irrigation water dissolves calcium carbonate and soluble salts in the soil. Since calcium carbonate is relatively insoluble, it accumulates in the topsoil leading to additional salt deposition (originally from the irrigation water) and water logging.

In this context this paper analyses the environmental performance of a cotton yarn manufacturer using the Life Cycle Assessment (LCA) method. The study compares the environmental impacts related to the production of cotton yarn from cultivation to washing and drying, when cotton is supplied by four companies sited in four different countries (Egypt, China, India and the USA). The environmental impact of the cotton yarn production stages will be analysed in order to evaluate the percentage impact at this stage in comparison with the cultivation stage. Moreover the cultivation scenarios analysis represents a decision-support tool to the companies seeking more sustainable cotton yarn production.

The paper is organised as follows: Sections 2 and 2.1 contain a literature review regarding respectively the development of sustainable supply chain and the use of LCA in the textile field (especially for the cotton production); Section 2.2 presents a description of the research approach proposed in this work; in Section 3, the case study of an international company has been reported. The results have been explained in Section 4 and discussed in Section 5. Finally, Section 6 reports the conclusions.

2. Development a green and sustainable supply chain

Many works (more than 300) have been published in the last 15 years on the topic of green or sustainable supply chains (Seuring, 2013). In these papers environmental dimension dominates, in comparison with social and economic aspects, and LCA type of studies and respective data form the backbone of the environmental debate (Seuring, 2013). Dillyick and Hockerts (2002) highlighted that a robust *Green supply chain* strategy should rely on the long–term correlation among the three dimensions of the sustainability: economic, environmental and social sustainability. Particularly, the *Green Supply Chain* strategies determine pressures on the supply chain emphasizing the demand for sustainable products. As sustainable management practise and systems require an intensive coordination to be established along the chain agents, the *Green Supply Chain* is expected to strengthen the vertical coordination which characterizes the chain (Omta et al., 2001). To contribute to the comprehension of this process it is worth to refer to the *focal company*, i.e. a company which due to multiple reasons is able to direct the activity of the most of chain agents. Actually an outcome expected of the *Green Supply Chain* strategies diffusion is the enhancement of the sustainability degree of the chains engaged. The pressure toward sustainability can be conceptualized in terms of elaboration of supply chain management. Seuring and Muller (2008) point out that Government, stakeholders and customers give raise to pressures toward sustainability upon the focal company in a supply chain. The main types of pressures are: Legal demands/regulation; Customers demand; Response to stakeholders; Competitive advantage; Environmental and social pressure groups; Reputation loss. As a consequence the focal the focal company has to take into account a long part of chain and needs information on the environmental and social performance of the chain agents (Suering and Müller, 2008). To some extent the increased necessity of coordination and the demand for detailed information is similarly determined by safety and quality strategy (Martino and Perugini, 2006). According to Seuring (2004), co-operation is the only way for companies to improve the competitiveness of the chain while reducing environmental burdens. In that work, the author analysed five case studies from the textile industry highlighting that the focal company of a supply chain have to engage in a timely process to acquire access to all partners and form partnerships with them.

2.1. The environmental impact of cotton yarn supply chain: a literature review

Most literature on fibre crop LCAs is available on cotton (Kalliala and Nousiainen, 1999) as the dominant textile fibre crop. The purpose of these LCAs is either textile ecolabeling or comparison with synthetic fibres. The general conclusion is that the production of cotton consumes less energy than polyester, but demands far more water for irrigation of the crop. The negative effects on the ecosystem of the abundant use of pesticides and fertilisers (eutrophication, nitrate contamination, increase in soil salinity) is in favour of organic cotton cultivation. The impact of transportation on the LCA was concluded to be very low due to bulk shipments. Cotton processing is largely mechanised, although in some parts of the world cotton is still harvested by hand. Specialised machinery has been developed for the harvesting of seed cotton, which either leaves the plants on the field or returns the trash after stripping. It is important for the fibre quality that the leaves are removed, so application of chemicals for defoliation is common practice.

Some earlier studies on the impact of cotton production were limited to the impact at the industrial stage only (e.g. Ren, 2000), leaving out the impact at the agricultural stage. Other cotton impact studies use the method of life cycle analysis and thus include all stages of production, but these studies are focussed on methodology rather than on the quantification of the impact (e.g. Proto et al., 2000; Seuring, 2004). Other studies that go in the direction of what we aim at in this paper are the background studies for the cotton initiative of the World Wide Fund for Nature (Soth et al., 1999; De Man, 2001). The reports can only be seen as a first sketch of the size and nature of the issue. They are a preliminary synthesis of existing scientific data. However, the fact findings show clearly that cotton is a relevant factor for the destruction of freshwater ecosystems on a regional as well as on a global scale. Although it can be assumed that cotton pesticides have severe effects on wildlife, little information could be accessed in which investigations proved clear evidence of documented fish or bird mortality due to pesticides. Particularly, Chapagain et al. (2006) highlight that cotton consumption is responsible for 2.6% of global water use. As a global average, 44% of the water use for cotton growth and processing is not for serving the domestic market.

Regarding energy consumption, Ismail et al. (2011) assert that the cotton SC is a set of processes with a great use of energy. They have evaluated the energy usage and costs for cotton ginning in Australia. Overall, it has been found that on average, the electricity usage per bale (kWh bale^{-1}) ranged between 46.5 and 58.55 kWh (167.4–210.8 MJ) bale^{-1}. Electricity and gas usage comprised of 61% and 39% of total energy use (MJ bale^{-1}) respectively. The drying process used 0.74–3.90 m^3 (28.64–150.93 MJ) of natural gas or 2.27–5.61 L of LPG gas (60.1–148.7 MJ) per bale. The overall thermal efficiency of the drying process was 8%.

There have been other LCAs conducted on cotton products, and the most recent was a study published by Grace (2009) that evaluated a cotton T-shirt. The study was limited in scope to Australian cotton and focused only on energy and greenhouse gas emissions.

Matlock et al. (2008) attempted to use LCA tools to assess the energy requirements for the cotton production phase from a global perspective, and one of the conclusions of their study was that a high degree of uncertainty exists in estimates for many regions of the world due to lack of publicly available data.

2.2. Research approach

In this context the study aims at developing a more sustainable cotton yarn supply chain of a clothing company (FM company: the *focal company*). According to Yin (2003) this work is a descriptive case study i.e. it presents a complete description of a phenomenon within its context.

The research process for this case study is similar to those used for other (empirical) research. In particular, the model proposed by Stuart et al. (2002) has been taken into consideration. This model consists in five-stage research process (see Fig. 1) and it explains how each step should be carried out when conducting case study research.

2.2.1. Research questions

This work addressed two research questions: a) What are the critical points of the supply chain from the environmental point of view; b) What important activities can be carried out by focal company and suppliers for reducing the environmental impact.

According to theoretical prediction (Seuring and Müller, 2008) specific pressures emerging on the demand side promote the adoption of sustainability management approaches. In particular the *focal company* complies with the Corporate Social Responsibility (CSR) program. CSR, as it is defined by the Commission of the European Communities, involves all the company's stakeholders and is developed on a voluntary basis: firms are encouraged to formulate and implement social programs and integrate ethical sensitivity into their policies and decision making.

2.2.2. Instrument development

This study is part of this CSR program and it has availed of the collaboration of the different conventional cotton cultivators which rank among the FM suppliers. Suppliers involved in this study are at the moment or have been in the last seven years providers of FM. These suppliers carry out the cultivation phases up to the ginning step (see Fig. 2) and are located in four production countries: Egypt, China, India and the USA.

2.2.3. Data gathering

We collected data from providers that FM company had from 2005 to 2012. The company used in that period 4 providers located in Egypt, 5 providers located in China, 4 providers located in India and 3 providers from the USA. The farms are located in the same region in each production country. Considering the small size of farms sample for each country the average values can not be considered significant and representative for the entire region of the country. We decided to analyse in detail only the best farm (in term of environmental impact) for each country. In particular, a LCA analysis has been carried out for every farm and the best farm of each country has been selected according to the minimum value of impact in terms of Ecoindicator99 total points. We can not generalize the result of the best farm with the results of the whole country even if this farm reflects the country region characteristics. This consideration is confirmed on the fact that all farms analysed in each region show similar values in term of inventory analysis (land occupation, type and quantity of fertilisers, pesticides, herbicides, defoliants, degree of mechanisation, …).

All farms analysed during survey process provided information related to both on-farm and off-farm applications. This process was initiated by sending an e-mail to all farmers, providing the relevant background information on the proposed study and an invitation to participate. A questionnaire was also developed for face-to-face (or by telephone) farmer interviews, which included questions on their on-farm cotton farming application rates, fuel consumption, and the type of machinery they typically use in their cotton production. Tables 1 and 2 summarized the questions proposed in the questionnaires for cultivation and production steps.

2.2.4. Data analysis

The methodology behind this study is known as Life Cycle Assessment and it involves an iterative process of assessing the environmental effects arising along the main chain, and it quantifies more precisely the impact of the most relevant items. LCA method has been used in order to quantify the environmental impact of manufacturer and suppliers. The results of the four companies have been compared, evaluating their respective strengths and weaknesses.

2.2.5. Dissemination

A comparison between the results obtained in this work with those obtained in some previous work (analysed in Section 2.1) has been carried out in order to validate this research.

Moreover the use of the LCA methodology allowed the “focal company” to evaluate and communicate the environmental impact of its processes and products. The work developed in this case study allowed the company to make the customers aware that the product is environmentally sound; in fact, the results obtained were introduced in the marketing campaign. The study also allowed the company to improve production performances in terms of efficient managing and use of resources.

3. Case study

In this work a specific cotton yarn supply chain of an important company in the field of the fashion, FM, has been analysed. The company FM (replacement of the original brand name that cannot be disclosed for commercial reasons) is a European multinational that is particularly sensitive to the environmental aspects and it will be considered the “focal company” of the supply chain analysed in this work.

3.1. Function unit, system boundary, and common assumptions

The functional unit chosen is 1 kg of dyed cotton yarn. Priority has also been given to the quantitative aspects, more than the immediate evaluation of quality, which is highly dependent on consumers' perceptions and the need to promote fashion products using different yarns with very specific technical characteristics. In defining the extension of the LCA it is crucial to establish the cut-off

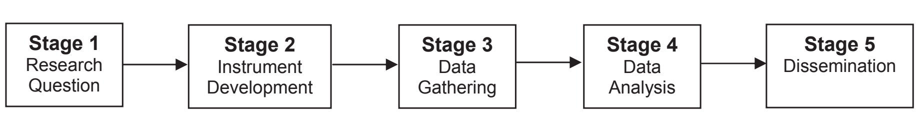

Fig. 1. The five stage research process model (modified by Stuart et al., 2002).

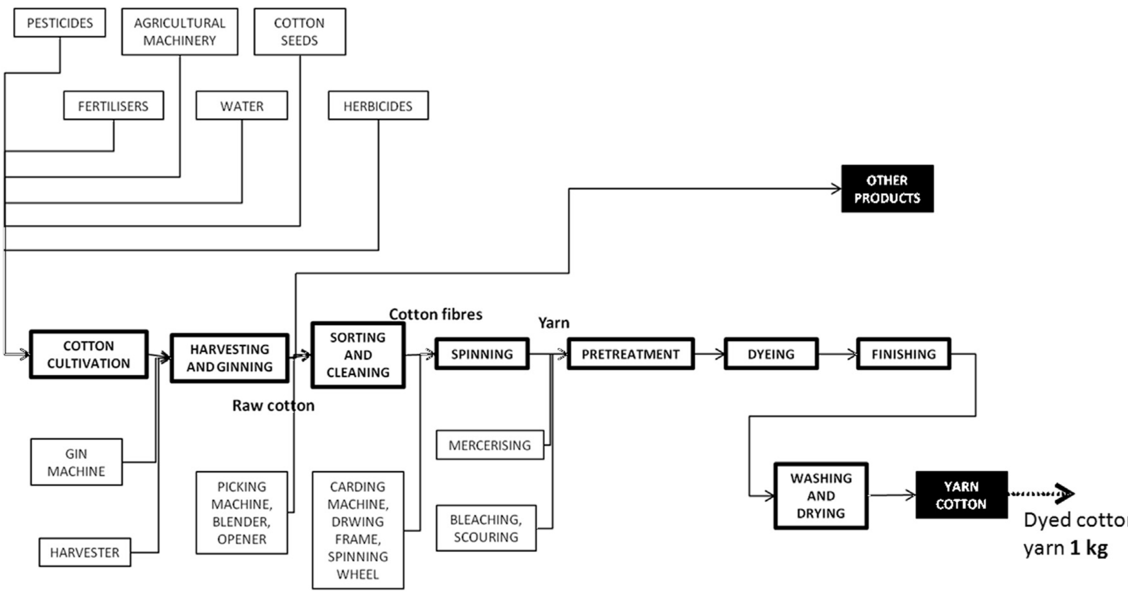

Fig. 2. Flow chart of the cotton supply chain.

rules that are the thresholds to identify the boundaries of the processes considered quantitatively significant and relevant.

It was decided to exclude any impact of less than 5% of the final value, for reasons of numerical strength and agility in gathering data (Bevilacqua et al., 2007). Regarding the types of activities, none has been excluded, in order to avoid systematic errors and there is been followed in the normal course of duties, without examining incidental or exceptional cases.

3.2. Life Cycle Inventory

Fig. 2 shows the flow chart of the cotton yarn production steps analysed.

The flow chart has been carried out considering the background and foreground systems respectively. The foreground system is highlighted in bold and it includes “cotton cultivation”, “harvesting and ginning”, “sorting and cleaning”, “spinning”, “pre-treatment”, “dyeing”, “finishing” and “washing and drying”. The background system is represented by all of the processes that regard the production of the used chemical substances, the agricultural machinery, fuels and all secondary operations.

In order to define each scenario, some sources have been used:

➢ **Primary** Sources of Information for chemical and mechanical treatments performed on cotton production: **questionnaires** sent to suppliers (see Section 2.1.3).

➢ **Secondary** Sources of Information for Cotton Cultivation: reports, analysis, national database. When this was impossible, the Ecoinvent v2 database (Frischknecht and Rebitzer, 2005), was used in this work.

The report “*Energy use LCA for global cotton production practices*”(Matlock et al., 2008), provided methodological and numerical

Table 1
Questionnaire outline proposed to suppliers (cultivation stage).

Inventory	Cultivation stage				
	Field preparation	Planting	Field operations (irrigation, weed and pest control, fertilization)	Harvesting	Ginning
Land Occupation	Where? Fields extend?				
Fertilisers		Green manure? Synthetic? Which ones? Quantities?			
Pesticides, Herbicides, Defoliants		Which ones? Quantities? Technique of Application?			
Irrigation		Requirements? Technique? Origin?			
Agricultural Machinery	Degree of Mechanisation? Which Operations? Energy and Fuel Consumptions?				
Production	Average annual yield? Utilization of residues? Secondary products manufacturing?				

Table 2
Questionnaire outline proposed to manufacturer (production stage).

Inventory	Production stage					
	Sorting and cleaning	Spinning	Pre-treatment	Dyeing	Finishing	Washing and drying
Machinery	Which machines? Productivity?					
Energy	Consumption? Electricity? Thermal energy? External, generated? Recovery of thermal energy?					
Chemicals			Automatic dosage? Biodegradable or Easily Bio-eliminable?			
Water	Origin? Any pre-treatment? Any recovery system?					
Logistic and packaging	Where are the phases located? Means of transport? Type of packaging?					
Products	Average annual production? Types of products? Waste estimate for each phase?					

Table 3
Cotton cultivation LCI at "best farms".

Farm description	Farm country			
	Egypt	China	India	USA
Regions	North	Xinjiang	North	Missouri
Region Cotton characteristics	North Egyptian cotton is famous for its long staple length combined with strong fibre that produces very fine cloth	Xinjiang cotton is entirely irrigated and appreciated for high quality, colour and fibre length. It also grows long-staple cotton.	The climate is adverse at the sowing season, with high temperatures, and the growing period is limited to six months. Double cropping 'cotton-wheat' is common with little time for tillage between the two crops.	Genetically modified (GM) varieties with resistance to bollworms and herbicides
Farm size (ha)	14.7	3,2	16.8	213
Productivity (kg/ha)	940	1100**	563	1013
Agricultural Machinery	Tractors; Harvesting: hand-picked	Small tractors; Harvesting: hand-picked	Tractors; Harvesting: hand-picked	Mechanized
Pesticides[a]	Organophosphates (0.95 kg/ha; ranging I-U); Pyrethroids (0.042 kg/ha; ranging II-U).	Parathion (U/la; 0.5 kg/ha°); Pyretroid (ranging II-U; 0.5 kg/ha°); Organophosphorus (0.5 kg/ha°)	Monocrotophos (Nuvacron,Ib; 0.46 kg/ha*****), endosulfan (Thiodan, II; 0.39 kg/ha*****), chlorpyriphos (Dursban, II; 1.12 kg/ha), dimethoate (Rogor, II; 0.9 kg/ha), fenvalerate (Fenvel, II; 0.1 kg/ha), cypermethrin (Radar, Ib; 0.125 kg/ha), Imidacloprid (Confidore, II; 0.05 kg/ha), spinosad (Tracer, U; 0.014 kg/ha*****)	Carbamate 0.7 kg/ha***** (ferbam/parathion, U/la); Organophosphates (1.35 kg/ha°; ranging I-U); Pyrethroids (0.0102 kg/ha°; ranging II-U).
Herbicides[a]	Glyphosate (U; 0.59 kg/ha), diuron (U; 0.66 kg/ha)	Caparol (prometryn, lll; 0.74 kg/ha***), Roundup (glyphosate, U; 0.91 kg/ha***); Cotoran (fluometuron, U; 0.94 kg/ha***)	Fluchloralin (Basalin, III; 1.3 kg/ha), diuron (U; 1.1 kg/ha), pendimethalin (Stomp, III; 0.78 kg/ha)	Dinitroaniline (0.8 kg/ha); Benzoate (0.025 kg/ha); Phenoxy (0.04 kg/ha°); Triazine (lb; 0.1 kg/ha°); Glyphosate (U; 1.2 kg/ha); Bipyridium (lll; 0.047 kg/ha°).
Defoliants[a]	Not applied	MSMA (lll; 1.46 kg/ha***; applied on 5% of the total area)	Not applied	Diuron (U; 0.62 kg/ha****)
Fertiliser	Urea (0.074 kg/kg cotton); N-ammonium (0.04256 kg/kg cotton); N-nitrate (0.04256 kg/kg cotton); Phosphorus (0.041 kg/kg cotton), Potassium (0.047 kg/kg cotton)	Urea (0.05 kg/kg cotton°); N-ammonium (0.12 kg/kg cotton°); N-nitrate (0.05 kg/kg cotton°); Phosphate (0.077 kg/kg cotton°), Potassium (0.124 kg/kg cotton°)	N-ammonium (0.0444 kg/kg cotton); N-nitrate (0.0444 kg/kg cotton); Phosphorus (0.045 kg/kg cotton), Potassium (0.03 kg/kg cotton)	Urea (0.023 kg/kg cotton); N-ammonium (0.055 kg/kg cotton); N-nitrate (0.031 kg/kg cotton); Phosphorus (0.053 kg/kg cotton), Potassium (0.09 kg/kg cotton)
Water source	Irrigation from Nile river.	Rivers: 26%; Well, in ground: 74%**	Irrigation	No irrigation
Irrigation method	Flood irrigation	Flood irrigation	Flood irrigation	
Water consumed (l/hectare)	6.500.000 l/ha	4.270.000 l/ha°°	8.300.000 l/ha	1.500 l/ha
Electrical energy (kWh/kg cotton)	0.858 kWh/kg cotton	0.648 kWh/kg cotton	0.912 kWh/kg cotton	0.427 kWh/kg cotton
Diesel Fuel (l/ha)	317.4 l/ha	365.8 l/ha	351.2 l/ha	415.4 l/ha
Transport (ton*km/kg cotton)	0.285 (lorry 3.5–16 ton)	0.267 (lorry 3.5–7.5 ton)	0.326 (lorry 3.5–16 ton)	0.348 (lorry > 16 ton)

** Source: ICAC (2005).
*** Source: USDA (2005).
**** Source: Vargas et al. (2005).
***** Source: EJF (2007).
° Source: Ecoinvent (2007).
°° Source: Cotton Incorporated (2009) http://www.cottoninc.com/).
[a] World Health Organisation (WHO) toxicity class: Ia: extremely hazardous Ib: highly hazardous; II: moderately hazardous, III = slightly hazardous, U = Unlikely to be hazardous.

data on the use of mechanical energy, animals in cotton production, including both the textile fibres, and secondary products (seed, oil, waste) which can be obtained from the plant. A further source of qualitative and quantitative information was the BREF (Best Available Techniques Reference documents for the textile industry), consulted on the processes of pre-treatment, dyeing and finishing.

Table 3 shows the main information collected for the best farm in each country and the source used. Where the source is not indicated all the data were collected using the questionnaire. Unfortunately, many questionnaires were completed partially. In these cases (especially in China), for the missing data it was necessary to make use of other sources.

The allocation method of input flows is causal. This method weighs the flows in output according to their importance in the production chain. 90% of environmental impact has been allocated to cotton fibres and 10% to cotton seeds.

Moreover, it has been calculated that the oil obtained from the cotton seeds is equal to 15% of their weight and it has an average energy content of 39,600 MJ/t; the energy needed to process the seeds (2380 MJ/t), and to extract the oil (5045 MJ/t), must be subtracted from this value, obtaining a net energy content equal to 32,223 MJ/t. This value is multiplied by the weight of the cotton seed oil equal, in the Egyptian company, to 0.2655 kg, obtaining 8.555 MJ of energy content. The same procedure was used for the other three scenarios. In particular, the net energy content of the cotton oil (32,223 MJ/t) is multiplied by the weight of the oil itself, equal to 0.285 kg in the Chinese company, obtaining a value of 9.183 MJ. For the USA company the energy content of the cotton seeds was estimated in 8.7 MJ, with an oil seed production of 0.27 kg per 1 kg of cotton fibers. For the Indian company the energy value of cotton seeds was calculated on the basis of a production of 1.6 kg of seeds per 1 kg of cotton fibers, which corresponds to 0.24 kg of cottonseed oil, equal to a net energy content of 7.733 MJ.

Table 4 summarized the main data obtained from the cotton yarn producer.

4. Life Cycle Impact Assessment

One of the challenges in conducting a meaningful comparison between different methodologies is the selection of the weighting method. In this work IPCC 2007 and Ecoindicator99 (H/A, Hierarchist Method) methods were tested.

Using the IPCC 2007 method, the greenhouse effect has been assessed, by measuring the Global Warming Potential of crops in terms of CO_2 equivalent kg. The method, developed by the International Panel of Climate Change, is based on the values of Global Warming Potential (GWP) calculated for each greenhouse gas, i.e. the relationship between the contributions to the greenhouse effect caused by the substances used and carbon dioxide.

Table 4
Data collected using questionnaires for the production phase.

Production phases	Description
Production	20,000 kg/day, 4,200,000 kg/year Finished goods: dyed yarn 5000 kg/day, mercerized yarn 9000 kg/day, others 6000 kg/day
Treatment characteristics and chemical consumption	Mercerising: caustic soda 0.6 kg/kg_yarn Technique: mercerising with tension in cold bath; bath recovery and re-use. Bleaching: Hydrogen Peroxide 30 g/kg_yarn, Sodium Hypochlorite 50 g/kg_yarn Dyeing: Reactive Dyestuff 1–140 g/kg_yarn, Sodium Carbonate 1–2 g/kg_yarn, Salt 20–70 g/kh_yarn Liquor Ratio: 1/15 Finishing: Softeners 1–2 g/kg_yarn, Fixative 1–2 g/kg_yarn Washing and Drying: Wetting Agents 1 g/kg_yarn, Soap 0.5 g/kg_yarn Water from 20° to 60 °C, basic/neutral pH; both mechanical and thermal drying
Water consumption	180 l/kg_yarn Industrial well; 15% recovery and re-use Softening treatment to remove calcium and magnesium salts Discharging: 2500 m^3/day on a production of 14,000 kg/day
Energy consumption	Dyeing: 2 kWh/kg_yarn, methane 1 m^3/kg_yarn Electric energy 100% from external suppliers Thermal energy from heat exchangers (heat from water discharging, dyeing bath cooling)
Logistics	Transport: sea freight, transport by truck Packaging: cardboard, 15% on yarn weight

In Ecoindicator99 methods 13 impact categories have been analysed. This method is damage-oriented.

In particular Ecoindicator99 classifies impact in three damage macro-categories: ***Human Health (HH), Ecosystem Quality (EQ)*** and ***Resources (R).***

Human Health (HH) includes damage caused by all substances that have an impact on respiration (organic and inorganic compounds), carcinogenesis, climate change and ozone layer. Ionizing radiation is also included in this category (Frischknecht et al., 2000). These types of damage are expressed in DALYs (Disability Adjusted Life Years).

Ecosystem Quality (EQ) includes damage to ecosystem quality and is expressed as the percentage of species of plants estimated to have disappeared from a certain area due to changing environmental conditions (PDF * m^2 * yr, PDF = Potentially Disappeared Fraction of plant species).

In this impact category the ecotoxicity is expressed as the percentage of species that live in a certain area under stress. Acidification and eutrophication are treated in a single impact category and are modelled using the target species (vascular plants). The impact arising from the use of land and its transformations are based on empirical data on the presence/absence of vascular plants, which is a function of land use and size of the area. Both local and regional is modelled (Hofstetter, 1998);

The Resources (R) category includes extracting and using mineral resources and fuels. The extraction of resources is related to parameters that indicate the quality of mineral resources and fossil remains in the fields. The impact of this category is quantified in terms of increased energy needed for future extractions (MJ surplus energy).

The results obtained from this study have been divided considering the two main players of the cotton yarn supply chain: the cotton suppliers (cultivation phase, Section 4.1) and the cotton yarn manufacturer (production system, Section 4.2).

4.1. Cotton suppliers (cultivation phase)

The cotton cultivation phase takes into consideration the steps: “Cotton Cultivation”, “Harvesting and Ginning”, and the related input and output as shown in Table 1.

Table 5 shows the characterization of the cultivation phase in the four companies in terms of Ecoindicator99 and IPCC2007 LCIA categories.

4.2. Cotton yarn manufacturer (production system)

Regarding cotton yarn production, the FM production system has been analysed. Table 2 shows the production steps analysed: “Cleaning and Sorting”-“Spinning”-“Pretreatment”-“Dyeing”-“Finishing”-“Washing and Drying” and the related input. Table 6 shows the characterization of the cotton production phase using Ecoindicator99 method while Fig. 3 shows the relative impact of each production phase using IPCC 2007 method (GWP100a). Particularly in Fig. 3 the flows that provide the most important impact for each production step have been highlighted.

5. Discussion

Information obtained from the cotton suppliers (cultivation phase) will be discussed in Section 5.1 while the performance of cotton yarn manufacturer (production system) will be discussed in

Table 5
Cultivation characterization.

Methods	Cultivation scenarios			
Ecoindicator99: LCIA category	Egypt company	China company	India company	USA company
Ecosystem quality – acidification & eutrophication	1.54E-3 point[a]	2.43E-3 point	2.95E-3 point	2.06E-3 point
Ecosystem quality – ecotoxicity	1.84E-3 point	1.77E-3 point	2.71E-3 point	2.05E-3 point
Ecosystem quality – land occupation	0.29 point	0.73 point	1.43 point	0.84 point
Ecosystem quality – stored ecotoxicity	2.61E-6 point	1.98E-6 point	1.27E-6 point	1.52E-6 point
Ecosystem quality – total	***0.29 point***	***0.74 point***	***1.44 point***	***0.84 point***
Human health – carcinogenics	1.04E-3 point	1.66E-3 point	1.52E-3 point	1.74E-3 point
Human health – ionising radiation	9.84E-7 point	1.53E-6 point	1.19E-6 point	1.57E-6 point
Human health – climate change	3.57E-3 point	4.11E-3 point	4.96E-3 point	3.48E-3 point
Human health – ozone layer depletion	0 point	0 point	0 point	0 point
Human health – respiratory effects	1.5E-2 point	2.45E-2 point	2.9E-2 point	2.29E-2 point
Human health – stored carcinogenics	1.36E-7 point	1.63E-7 point	8.73E-8 point	8.7E-8 point
Human health – stored ionising radiation	0 point	0 point	0 point	0 point
Human health – total	***1.96E-2 point***	***3.03E-2 point***	***3.55E-2 point***	***2.82E-2 point***
Resources – fossil fuels	1.55E-3 point	1.66E-3 point	2.25E-3 point	1.74E-3 point
Resources – mineral extraction	1.3E-8 point	1.4E-8 point	1.88E-8 point	1.46E-8 point
Resources – total	***1.55E-3 point***	***1.66E-3 point***	***2.25E-3 point***	***1.74E-3 point***
IPCC 2007				
Climate change – GWP 20a	0.63 kg CO_2 eq	0.73 kg CO_2 eq	0.89 kg CO_2 eq	0.63 kg CO_2 eq
Climate change – GWP 100a	0.63 kg CO_2 eq	0.72 kg CO_2 eq	0.89 kg CO_2 eq	0.62 kg CO_2 eq
Climate change – GWP 500a	0.52 kg CO_2 eq	0.57 kg CO_2 eq	0.77 kg CO_2 eq	0.56 kg CO_2 eq

[a] All values have been expressed in Eco-points. Specifically, an eco-point is the distance to target principle, or the difference between the total impact in a specific area and the target value (the target values in the original Ecopunkten Method were derived from of the Swiss government target values).

Section 5.2. Moreover results collected by Ecoindicator99 and IPCC 2007 will be analysed one by one.

5.1. Discussion on cotton suppliers (cultivation impact)

5.1.1. Analysis of Ecoindicator99 results

5.1.1.1. Ecosystem Quality. Table 5 highlights that the Indian supplier is always the worst in terms of Ecosystem Quality due to high fuel consumption and lower productivity. The exception is the LCIA category stored eco-toxicity, due to lower overall volumes of fertilizer products used.

Referring to Ecoindicator99, the category "land occupation" is responsible for the ecosystems quality. The impact category "land occupation" is influenced by the productivity per hectare. The Indian suppliers generally have the most impact for its low productivity. Other causes are detectable in using water for irrigation and, above all, in using synthetic fertilizers, which affect the quality of the soil by reducing drastically the productivity. These results confirm the De Man (2001) analysis regarding the sustainability of cotton supply chain in India.

In the Ecosystem Quality category the United States suppliers have an impact value greater than China and Egypt suppliers, due to the characteristics of intensive agriculture practiced in the areas of the cotton belt.

The category "eco-toxicity" refers to the complex effects that toxic substances commonly found in anthropogenic products have on the ecosystems, when they accumulate in plant and animal organisms and persist in the food chain. The causes of the eco-toxicity problems are the phosphorus based synthetic fertilizers used in fields during ploughing and pest control. The first entry of impact is the "single super phosphate", used in order to produce fertilizers.

5.1.1.2. Human Health. Even for the category Human Health the major impact factors are synthetic fertilizers, based on phosphorus,

Table 6
Cotton yarn production characterization (using Ecoindicator99).

Methods	Production step				
Ecoindicator99 - LCIA category	Cleaning Sorting and Spinning	Pretreatment	Dyeing	Finishing	Washing and Drying
Ecosystem quality – acidification & eutrophication	8.66E-4 points[a]	5.82E-4 points	9.93E-4 points	5.84E-4 points	2.54E-4 points
Ecosystem quality – ecotoxicity	1.3E-3 points	6.72E-4 points	1.31E-3 points	4.25E-4 points	5.4E-4 points
Ecosystem quality – land occupation	9.98E-3 points	2.82E-4 points	7.51E-4 points	1.12E-3 points	2.85E-4 points
Ecosystem quality – stored ecotoxicity	1.62E-4 points	1.57E-4 points	7.52E-5 points	6.49E-5 points	9.02E-5 points
Ecosystem quality – total	1.21E-2 points	1.54E-3 points	3.05E-3 points	2.13E-3 points	1.08E-3 points
Human health – carcinogenics	7.13E-4 points	8.43E-4 points	7.63E-4 points	2.68E-4 points	1.0E-3 points
Human health – ionising radiation	1.12E-4 points	4.4E-5 points	1.61E-5 points	9.19E-6 points	2.04E-5 points
Human health – climate change	3.49E-3 points	1.45E-3 points	6.62E-3 points	2.75E-3 points	6.89E-4 points
Human health – ozone layer depletion	1.25E-6 points	4.32E-7 points	9.83E-6 points	7.43E-6 points	8.17E-7 points
Human health – respiratory effects	1.0E-2 points	4.9E-3 points	1.03E-2 points	5.68E-3 points	2.39E-3 points
Human health – stored carcinogenics	2.28E-3 points	1.6E-3 points	6.9E-4 points	4.62E-4 points	6.73E-4 points
Human health – stored ionising radiation	0 points	0 points	0 points	0 points	0 points
Human health – total	1.44E-2 points	7.24E-3 points	1.77E-2 points	8.72E-3 points	4.1E-3 points
Resources – fossil fuels	1.9E-2 points	6.09E-3 points	0.18 points	0.14 points	3.23E-3 points
Resources – mineral extraction	4.87E-4 points	5.21E-4 points	2.92E-4 points	2.69E-4 points	4.17E-4 points
Resources - total	1.95E-2 points	6.61E-3 points	0.18 points	0.14 points	3.65E-3 points

[a] All values have been expressed in Eco-points. Specifically, an eco-point is the distance to target principle, or the difference between the total impact in a specific area and the target value (the target values in the original Ecopunkten Method were derived from of the Swiss government target values).

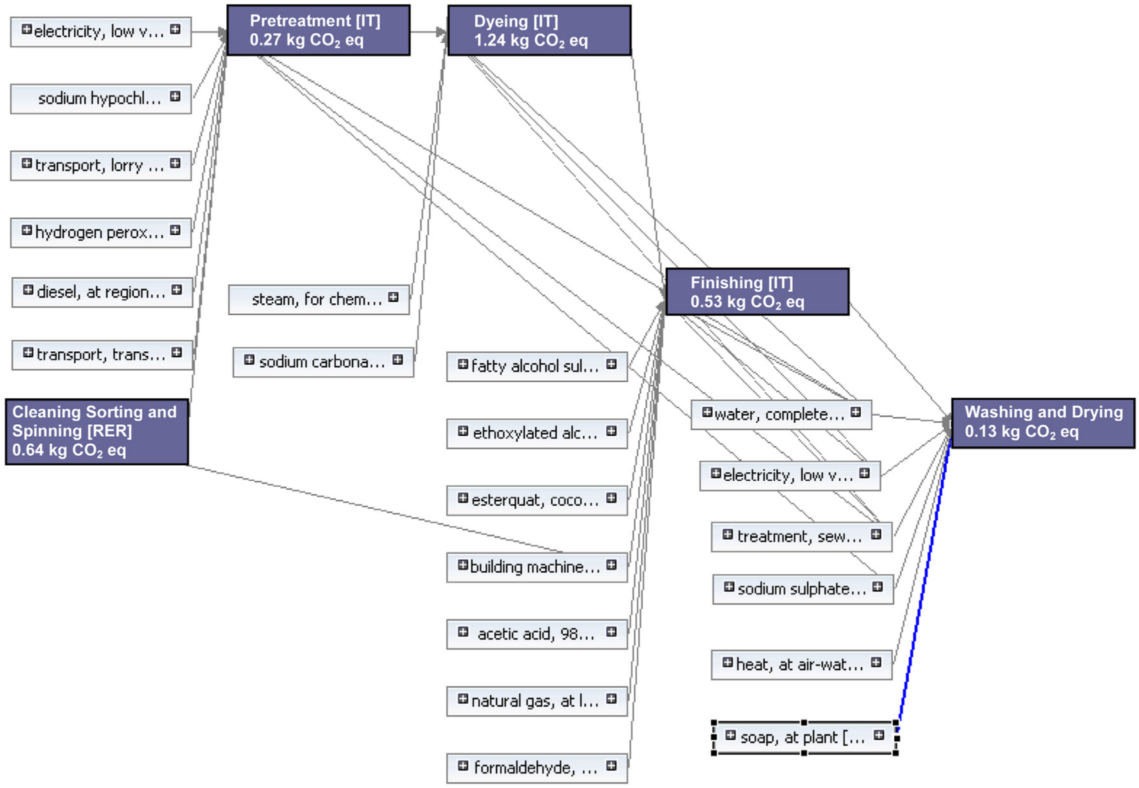

Fig. 3. Impact of each cotton yarn production steps.

nitrogen, potassium and their use. In particular, the principal effects which they cause are respiratory problems (about 80%) such as irritation and inflammation of the airways, asthma, bronchitis, lung diseases.

In the analysis done by the Ecoindicator99, the category Human Health is greatly influenced by respiratory effects, related to both acute (exposure to high doses of a toxic substance on a single occasion) and chronic poisoning (repeated exposure to toxic agents over longer periods, with symptoms which can appear after a long time or in future generations).

This study shows that the Human Health category is much more problematic in the Indian supplier than in the others (see Table 5). In fact, according to EJF (2007), a large proportion of all human communities, involved in the use of the most dangerous pesticides, lives in India, where the almost total absence of security measures and poor quality protection equipment (very often unavailable or with a prohibitive cost), is causing a real massacre of human lives. In response to the serious health and environmental risks posed by hazardous pesticides, some countries have either banned or restricted the application of specific agrochemicals in crop production. However, at present, only 17 countries have imposed a ban on any of the top 10 hazardous pesticides used in global cotton production (PAN, 2006).

The United States supplier has the greatest impact with regard to carcinogens, due to the amount of chemicals used and also their quality: the insecticide "parathion" is considered extremely dangerous by the World Health Organization and it is still widely used in the cultivation of the cotton belt.

Finally the Chinese supplier, characterized by increased productivity, but also by the intense application of synthetic fertilizers, pesticides, herbicides or defoliants, has a top position in each comparison and it is significantly superior to the others in the category Stored Carcinogenic, referring to persistent toxic substances in the ground.

5.1.1.3. Resources. The third and final category of Ecoindicator 99 is the exploitation of natural resources. The totality of the impact is attributable to the use of non-renewable energy: fossil fuels and electricity consumption related to the agricultural operations and production of chemicals used. The strong mechanization of USA agriculture and the low use of machinery in Africa (in Egypt strand collection is done entirely by hand) can account for different levels of impact in these suppliers. The results obtained for USA suppliers, in terms of fossil fuels and electricity consumption, are similar to the results obtained in Ismail et al. (2011) analysing Australian cotton suppliers.

In the category related to natural resources consumption, the gap between the types of impact is less clear, due to the different productivity of the plantations. Principally they are caused mainly by two processes: the baling of the fibres of cotton, and irrigation farming. In the Egyptian, United States and Chinese suppliers the baling process prevails over the irrigation with a percentage equal to approximately 60%. Conversely, regarding the Indian suppliers, the irrigation process determines 55% of resource impact.

Regarding the category natural resources we must underline that the intensive use of water sources is ecologically unsustainable in various cotton production areas. Cotton requires large amounts of water both for cultivation and processing. Particularly in China and Egypt the irrigation sources are severely threatened as rainfall during the growing season is less than 100 mm (Gillham, 1995). In these regions it could be necessary to switch from a flood irrigation to a drip irrigation system. The water efficiency (water that reaches the plant/water at source $\times 100\%$) of the flood-or-furrow system is approximately 40%, due to evaporation, seepage losses and mismanagement (Gleick, 1993). Elements of mismanagement include: allowing (much) more water than the plants require which leads to runoff; unworkable distances between the water source and application, and leaking irrigation canals. An important factor related to the inherent low water efficiency of the flood-or-furrow system is that it is difficult to fine-tune the irrigation system to the needs of the crop. Using *drip irrigation a* branched polypropylene pipe system doses the amount of water required by the plant and places the water exactly at the plant's root. The technique is relatively expensive. For example, in the USA the cost is roughly 200–600 US$ per hectare per year (Thompson and Enciso-Medina, 2002). Drip irrigation can reduce the amount of water used by at least 16–30% compared to the most efficient flood-or-furrow systems, and is likely to be much higher when compared to many poorly functioning flood-or-furrow systems. The average water efficiency of drip irrigation is 90–98% (TWDB, 2003).

5.1.2. Analysis of IPCC 2007 results

Analyzes carried out have shown that the predominant causes of the greenhouse effect are due to fuel consumption and artificial fertilizers. Particularly, in Indian company fuel consumption and artificial fertilizers take about 47% and 31% of the total CO_2 Eq. emission. Comparing the four cultivation systems it is possible to highlight that the productivity influences the value of the environmental impact associated to each country. For example the Indian suppliers are characterized by an average productivity of *563 kg/ha*, compared to the about *1100 kg/ha* of the Chinese suppliers. For these reasons, the greenhouse effect with the highest value is produced by the Indian scenario, with *0.89 kg* of CO_2 *equivalent* (per 1 kg of cotton), the Chinese scenario is the second, with *0.72 kg* of CO_2 Eq., equal to 81,66% of the first scenario. Referring to the Egyptian and United States suppliers, they are similar and equal to *0.63 kg* of CO_2 *equivalent* and *0.62 kg* of CO_2 *equivalent*.

Artificial fertilizers are the first item of greenhouse effect in Egyptian and Chinese companies because of their extensive use, an inefficient irrigation techniques and the lack of rotation with other unprofitable crops. For example, for the Cultivation System in Egypt, about 52% of impact calculated using IPCC 2007 refers to chemical nitrogenous fertilizers such as ammonium nitrate, urea, calcium nitrate and ammonium sulphate. Ammonium nitrate is also the first item of impact in the other scenarios because of its contribution in field preparation processes and transport by trucks.

Limited increases in atmospheric CO_2 could favour cotton yields. The impact of climate change on rainfall is likely to be positive in China, in India and in the south-eastern United States. The crop is, however, sensitive to water availability, particularly at the height of flowering and boll formation. Rising temperatures favour cotton plant development, unless day temperatures exceed 32 °C. Limited increases in atmospheric CO_2 also favour the cotton plant's development. Overall, the negative impact of climate change on cotton production relates to the reduced availability of water for irrigation, in particular in Xinjiang (China). A number of adaptation strategies include:

- Flexibility of sowing dates;
  -Minimize soil tillage on cotton cropland in order to prevent soil to air emissions;
- Minimize the use of synthetic fertilizers in general and nitrogen fertilizers in particular, because these are an important source of N_2O emissions;
- Minimize the burning of cotton crop residues where still applied, and recycle these for soil fertility management when not used as a fuel for cooking and heating;
- Maximizing plant diversity.

5.2. Discussion on cotton yarn manufacturer (production impact)

5.2.1. Analysis of Ecoindicator99 results

5.2.1.1. Ecosystem Quality. From "***Ecosystem quality***" point of view the production step "Cleaning, Sorting and Spinning" provides the highest contribution. *Spinning* is the process of converting fibers into yarn and is the production step that uses the most energy. Analysing the sub-categories we can highlight that the high value of "Ecosystem quality-ecotoxicity" is essentially due to the demand for electricity. The main opportunities for energy savings will reside in the largest energy-using processes and products. Some textile machinery manufacturers (www.rieter.com, *2013) highlight* the possibility to reduce electricity consumption by 5%–10% optimizing machine drafting drive. This optimization will allow the company to considerably reduce the environmental impact of spinning phase. As shown in Table 7, the FM company can reduce the Spinning phase CO_2 emission by 31.5% decreasing the electrical energy consumption by 5%.

The company analysed did not highlight significant difference in the energy consumed during the sorting and cleaning step when using different cotton sources.

5.2.1.2. Human Health. Table 6 highlights that the Dyeing step is responsible for the most important environmental impact in terms of "Human health" (34% of the total score) and "Resources" (51.5% of the total score).

Regarding the "***Human health***" category the main contribution is provided by the "Human health-respiratory effects" (58%). This impact is essentially connected to reactive reagents and pigments, electrical and thermal energy, water and wastewater with relative treatment used in the dyeing process. Therefore, the removal of colour from wastewater is often more important than the removal of the soluble colourless organic substances. The removal of the dyes from the textile wastewater is often very costly, but a stringent environmental legislation has stimulated the textile sector in developing wastewater treatment plants. The wastewater that flows in the drains corrodes and scales up the sewerage pipes. If allowed to flow into drains and rivers it effects the quality of the drinking water in hand pumps making it unfit for human consumption. It also leads to leakage in drains increasing their maintenance costs. Moreover, all the organic materials present in the wastewater are of great concern in water treatment because they react with many disinfectants especially chlorine. Chemicals evaporate into the air we breathe or are absorbed through our skin and show up as allergic reactions and may cause harm to children even before birth.

5.2.1.3. Resources. Regarding the ***Resource*** category the main contribution is provided by "Resource-fossil fuels" (almost 100%). This impact is connected to the natural gas used during dyeing processes. About this aspect we must highlight that energy

Table 7
Energy optimization of spinning production phase.

Spinning	Characterization			
	CO_2 kg eq.	Ecosystem quality	Human health	Resources
− 5% (electricity consumption)	0.438 (−31.5%)	0.00808 (−33%)	0.00386 (−73%)	0.0125 (−35%)
− 10% (electricity consumption)	0.418 (−34.6%)	0.00802 (−33.8%)	0.00363 (−74.7%)	0.0119 (−38.8%)

Table 8
Energy optimization of dyeing production phase.

Dyeing	Characterization			
	CO_2 kg eq.	Ecosystem quality	Human health	Resources
−15% (electricity consumption)	0.856 (−30.9%)	0.0007 (−77%)	0.0061 (−66%)	0.1658 (−7.8%)
−30% (electricity consumption)	0.841 (−32.2%)	0.0007 (−77%)	0.0060 (−66%)	0.1652 (−8.2%)
−20% (natural gas consumption)	0.796 (−35.8%)	0.0006 (−80.1%)	0.0052 (−70.6%)	0.139 (−22.7%)
−40% (natural gas consumption)	0.722 (−41.7%)	0.0006 (−80.4%)	0.0050 (71.7%)	0.1119 (−37.8%)

efficiency and waste minimisation are often closely linked. Many of the energy savings that may be made in any facility relate to staff awareness of the need to conserve energy and their attention to small measures that can collectively make a big difference. Heating and lighting energy requirements can be reduced through sensible conservation measures. Dyeing and finishing facilities use significant quantities of energy for steam, power for motors, direct heat for drying, air compressors, air conditioning and cooling. Each facility should consider and quantify the energy usage of its processes and its overall energy costs. Options to reduce energy consumption that FM company is considering are:

- Recover cooling water and use it as heated input water.
- Return steam condensate to boilers.
- Reuse different process waters.
- Examine the efficiency of existing heat exchangers.

Several studies (Kocabas, 2009; Fan et al., 2011; DOE, 2008) highlight the possibility to reduce electrical consumption by 15%–30% and natural gas consumption by 20%–40% integrating these solutions in Dyeing and Finishing processes. From environmental point of view these solutions may produce important results (see Tables 8 and 9). As shown in Table 8, the FM company can reduce the dyeing phase CO_2 emission by 35.8% decreasing the thermal energy consumption by 20%.

5.2.2. Analysis of IPCC 2007 results

IPCC2007 method highlights that “Dyeing” (44% of the total impact) and “Cleaning, Sorting and Spinning” (23% of the total impact) are the two most important production steps in terms of GHG emissions.

80% (1.002 $kgCO_2$ eq.) of the Dyeing step emissions are due to the significant use of natural gas for steam, power for motors and direct heat, while 74% (0.476 $kgCO_2$ eq.) of the GHG emissions of the Spinning step is essentially due to the consumption of electrical energy.

The Finishing step is also important in terms of GHG emissions (19% of the total impact). We took into consideration, as finishing operations, on the basis of the questionnaire, both chemical and mechanical processes such as the application of fixative and softeners on the cotton yarn.

The impact causes during the finishing step is due to the energy consumption, chemicals applied on the yarn, the water consumed and its disposal.

Pretreatment processes on cotton yarn concern mercerization (carried out on 45% of the total production) and bleaching activities. The main environmental impact is caused by water consumption with softening and disposal processes, electrical energy and chemicals used during mercerization and bleaching phases.

Also the impact of Washing and Drying phases is influenced by the consumption of electrical energy, thermal energy used during drying processes and water used for washing.

6. Conclusions

This research aims at assessing the environmental impact associated with the cotton yarn supply chain, analysing raw material coming from many departments, with the collaboration of different firms, which are among the suppliers of FM. The initial background material is external to the company itself: regulations, reports, analyses developed by international bodies, including the European Parliament. A great part of the data was obtained by subjecting questionnaires to the FM suppliers. Strong support by the leader company was essential to overcome the reluctance of some stakeholders in providing data. According to Seuring and Muller (2004), inhumane working conditions or contamination of the (local) environment could be frequently a problem for obtaining information from suppliers. The collaboration between several stakeholders made this work useful to increase the environmental consciousness of the employees and of the supply chain operators involved along the production process.

Answers to the research questions (What are the critical points of the analysed supply chain? What important activities can be carried out for reducing the environmental impact) can be provided for the main supply chain players: cotton suppliers and focal company.

6.1. Main considerations about cotton suppliers

Ammonium nitrate is the first item of greenhouse effect in all supplier companies because of its extensive use, an inefficient irrigation techniques and the lack of rotation with other unprofitable crops.

The total impact of the Egyptian supplier is smaller than the others, equal to 0.31 points (Table 5), thanks to a limited use of agricultural machinery. In Egypt a proper use of fertilizers, in addition to traditional methods of maintaining soil fertility such as planting clover before cotton, incorporating the organic fertilizer into the soil at the time of preparation for planting and inserting legumes in crop rotation, is essential in order to improve the productivity and quality of the crops.

Table 9
Energy optimization of finishing production phase.

Finishing	Characterization			
	CO_2 kg eq.	Ecosystem quality	Human health	Resources
− 15% (electricity consumption)	0.3918 (−26%)	0.0005 (−97%)	0.0018 (−79%)	0.1369 (−2.2%)
− 30% (electricity consumption)	0.3776 (−28.7%)	0.0005 (−97.3%)	0.0017 (−80.8%)	0.1364 (−25.7%)
− 20% (natural gas consumption)	0.3310 (−37.5%)	0.0005 (−97.5%)	0.0010 (−88.4%)	0.1102 (−21.3%)
− 40% (natural gas consumption)	0.2570 (−51.5%)	0.0003 (−98.5%)	0.0004 (−97%)	0.0829 (−40.7%)

Chinese company follows it, with 0.77 points. The Chinese suppliers are characterized by the increased application of chemical fertilizers and irrigation of almost all the land and also they have the highest productivity.

Regarding the category natural resources we must underline that the intensive use of water sources is ecologically unsustainable in various cotton production areas. Particularly in Chinese and Egyptian companies the irrigation sources are severely threatened. We highlighted in discussion section that in these companies it could be necessary to switch from a flood irrigation to a drip irrigation system.

The United States supplier, with an impact equal to 0.87 points, is in an intermediate position: agriculture is intensive, highly mechanized, but not as productive as the Chinese supplier, because of lower soil fertility, further impoverished by heavy use of fertilizer products. The United States supplier has the greatest impact with regard to carcinogens (Table 5), due to the amount of chemicals used.

The Indian supplier shows the greatest environmental impact, with 1.48 points due to lower productivity. Other causes are detectable in using water for irrigation and, above all, in using synthetic fertilizers (based on phosphorus, nitrogen and potassium) which affect the quality of the soil by reducing drastically the productivity. In this country, cotton is undoubtedly one of the most important resources from the economic, nutritional (through secondary products derived from it, such as vegetable oil) and cultural point of view, but the conventional cultivation, which applies to its production has become highly problematic, both for the farmers directly involved and for the external costs of its impact on humans and the environment. This result is confirmed by EJF (2007) study in which the authors highlight that in many Indian cotton growing regions, acute poisoning has become a common phenomenon, with entire families at risk of contamination through pesticide drift and the contamination of drinking water and food sources. International clothing retailers should avoid sourcing textile products manufactured from cotton grown in association with the use of formulated products that fall into WHO classes Ia and Ib, or formulations of products in Class II. Customers may have an important role in asking clothing companies and retailers which pesticides were used in the production of the cotton and cotton products they sell. Moreover the National Governments of Cotton Producing Countries should ensure that all agricultural workers involved in cotton production have adequate access to protective equipment, and receive training in the responsible use of hazardous cotton pesticides.

6.2. Main considerations about the focal company

The production phase of cotton yarn provides an impact equal to 2.81, in terms of CO_2 kg-equivalent. This value underlines the higher impact of production phase in comparison to any cultivation scenario.

The most critical phases of yarn production are Dyeing and Spinning (listed in order of importance). The impact of Dyeing process is essentially connected to reactive reagents and pigments, electrical and thermal energy, while the impact of Spinning process is essentially due to the demand for electricity.

Regarding the reactive reagents and pigments impact we can highlight that tax incentive or a more stringent environmental legislation about the removal of the dyes from the textile wastewater may stimulate the textile sector in developing wastewater treatment plants.

Moreover, as showed in Tables 8 and 9, some upgrades and improvement in dyeing plants (recover cooling water, return steam condensate to boilers or reuse different process waters) could allow the company to reduce electrical energy (with a decrease in CO_2 by 32.2%) and thermal consumptions (with a decrease in CO_2 by 41.7%).

Regarding the spinning process the FM company is assessing the possibility to use a suction tube that reduce suction power. Each spinning position currently features a suction opening for extracting ends down and tangles. However, this is only needed in very few cases. The company can replace existing suction tubes with a suction tube that opens fully only when necessary. Considerable energy savings are achieved in conjunction with adjustable inverter control. As shown in Table 7 these techniques will allow the company to reduce electrical energy consumption and as a consequence CO_2 emission by 34.6%.

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