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Methods: The emissions defined in the EU Ecolabel scheme for textiles and bed mattresses were considered, and mid-point and end-point impact categories established within the guidance for the implementation of the EU Product Environmental Footprint (PEF) were also taken into account. The Life Cycle Assessment (LCA) methodology was adopted for carrying out the environmental analysis. Alternative scenarios were also investigated in order to evaluate sustainable improvements in PET yarn supplying and final disposing of PET fabric, while a Monte Carlo simulation was performed to assess sensitivity of results related to data uncertainty.
Results and discussion: Results show critical processes, like fiber and yarn production (for CO2), or dyeing and finishing (for VOCs, formaldehyde, and the water). The Chinese electricity mix considered for PET yarn production is responsible of the high contribution for almost all the PEF impact categories analysed. This is due to the hard coal burning referred to the process of electricity production.
Conclusions: Textiles sector has undertaken a constant restructuring and modernization process in Europe as reaction to the economic crisis. Italian textile industry plays a strategic role in Europe with leading brands in luxury clothing, dominant positions for indoor and in certain niches of technical textiles. Nowadays, in order to enhance competitiveness, textile companies are paying particular attention to environmental issue and sustainable productions, such as recycled PET products.
Recommendations: The results of the LCA performed on the 100% PET ticking could be useful for decision-making processes of Italian textile companies, in order to optimize the manufacturing processes, and gain competitive advantages from sustainable products.

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Environmental Analysis of Polyester Fabric for Ticking

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Recommendations: The results of the LCA performed on the 100% PET ticking could be useful for decision-making processes of Italian textile companies, in order to optimize the manufacturing processes, and gain competitive advantages from sustainable products.

Highlights

- The European textile industry consists mostly of SMEs with great resilience towards the use of new green technologies and eco innovations;
- In order to enhance competitiveness, textile companies should pay particular attention to environmental issue and sustainable productions;
- This paper aims to investigate the environmental impacts of a polyester fabric used as mattresses outer cover;
- Results show the possibility to improve the environmental performance of some processes such as: PET yarns production (the more impactful phase), the EoL phase, the dyeing yarn and the finishing fabric processes.

Keywords Life Cycle Assessment, Manufacturing Sustainability, Polyester, Textile Industry, Ecolabel

1 Introduction

The textile industry is divided into three major areas: production of textile fibers, production of woven and knitted fabrics by weaving and knitting, and transformation of such fabrics into final products (EPA 1997). Usually the chain is made up of different industrial sectors, with a series of incoming raw materials in various processes, and various output products with different characteristics depending on raw materials and use of final products (EURATEX 2014).

The European mill consumption of fibres in 2015 was 3,217,000 tons (3,051,000 tons in 2011), there was 174,480 companies, the amount of EU imports was 109.4 billion of Euro (in particular 28.6 for textile and 80.8 for clothing) and amount of EU export was 44.5 billion of Euro (in particular 21.8 for textile and 22.7 for clothing).

The main extra-EU imports of textile products, in 2015, was 14% yarns and threads, 21% woven fabrics, 23% technical textiles and 20% home textiles.

The main extra-EU exports of textile products, in 2015, was 9% yarns and threads, 28% woven fabrics, 27% technical textiles.

The main trading partners for the European Union in textile costumers, in 2015, was USA (2.7 billion Euro), China (1.9 billion Euro), Turkey (1.8 billion Euro); the main textile suppliers was China (9.6 billion Euro), Turkey (4.8 billion Euro), India (2.6 billion Euro).

The main trading partners for the European Union in clothing costumers, in 2015, was Switzerland (3.4 billion Euro) USA (3.1 billion Euro), Russia (2.1 billion Euro); the main clothing suppliers was China (30 billion Euro), Bangladesh (13.7 billion Euro), Turkey (9.4 billion Euro) (EURATEX 2015a, b).

In recent years, the slowdown of economic activities of the European Union has had a negative impact on the production of yarns and fabrics (EC 2010a). The development of the euro-Mediterranean area led to the relocation of production to the benefit of countries like Bulgaria and Romania, in a time when the euro showed a significant upward trend against the US dollar (EURATEX 2012).

Studies of European Apparel and Textile Confederation (EURATEX) with the Saxion Universities for the European Commission Enterprise and Industry, foresee that the textile industry, in Europe, will suffer a further drop, following the relocation of the production of large enterprises to the Asian region, in growing markets, due to trade barriers and difficulties to credit access for export and insurances of the enterprises. The European textile industry consists mostly of SMEs. They still have a great resilience and are trying to restructure and modernize, with the use of new green technologies and eco innovations, so they can adapt to changing market conditions and be competitive (EURATEX 2014). So, in order to enhance competitiveness, textile companies should pay particular attention to environmental issue and sustainable productions. The establishment of EU Ecolabel and Green Public Procurement (GPP) criteria represents an opportunity for textile companies that want differentiate their production by enhancing environmental, safety, technical and functional aspects (EC 2008, 2010c).

This paper aims to investigate the environmental impacts of a polyester fabric used as mattresses outer cover also called “tick” or “ticking” (Deliege and Nijdam 1998), by adopting the Life Cycle Assessment (LCA) methodology (Guinée et al. 2001, Baumann and Tillman 2004, Russell et al. 2005, EC 2010b). The paper also focused on some environmental issues identified within the EU Ecolabel scheme for bed mattresses (EC 2009) which are compliant with the criteria of the EU Ecolabel for textiles (Steinberger et al. 2009, EC 2012, JRC 2013, van der Velden et al. 2013).

To the knowledge of authors, there are no specific studies on the type of product analysed. A series of studies on tissues obtained from the raw material PET and other types of yarns were taken as references, having either the weaving process similar to that studied (Nieminen-Kalliala 2003, Dahllöf 2004, Steinberger et al. 2009, Koç and Çinçik 2010, De Saxce et al. 2012, Hasanbeigi et al. 2012, Lanoë et al. 2013, van der Velden et al. 2013) or those treating the European Ecolabel Bed Mattresses, LCA and criteria proposals final report for the EC (Deliege and Nijdam 1998).

The study engaged a textile company located in the South Italy, the ‘Apulia Stretch’ that produces home textiles, and, in particular, Jacquard fabric usually adopted for cover the external surface of the mattress.

2 Materials and Methods

2.1 LCA of a PET outer cover for bed mattresses

According to the LCA methodology (Guinée et al. 2001, Baumann and Tillman 2004), the potential environmental impacts of a PET outer cover for bed mattresses were investigated, by paying particular attention to the emissions defined within the EU Ecolabel scheme for textiles (JRC 2013). The LCA was carried out by following the step defined by the ISO standards (ISO 14040 2006, ISO 14044 2006): goal and scope definition; Life Cycle Inventory (LCI), Life Cycle Impact Assessment, (LCIA), interpretation of the results and sensitivity analysis.

As for goal and scope, the functional unit (FU) was 1 kg of 100% PET ticking, obtained using a Jacquard frame, and further laminated to a non-woven polypropylene (PP). The lifetime was assumed for 10 years (IPPC

2003a). As the cover of matrasses is not washable (no maintenance is made if not dusted or mechanically beaten), in the use phase no emissions were observed. For the end of life (EoL), the hypothesis of 50% disposed in landfills and 50% incinerated was assumed. As concerns the system boundaries, the life cycle was considered "form cradle to grave". The following stage were thus included:

a) resin fiber production (polymerization);

b) yarn production (spinning-twisting-texturing);

c) processes of weaving preparation: warping and dyeing;

d) weaving,

e) finishing (laminating);

f) packaging,

g) distribution and use;

h) end of life.

As concerns the geographical context the following hypothesis were considered according to the situation concerning the company involved in the study (Fig. 1) (Apulia Stretch 2015):

- fiber and polyester yarn were produced in China;
- the preparation of the yarn for weaving and the steps of dyeing and warping were carried out in Northern Italy;
- the steps of weaving, finishing, packaging were carried out in Southern Italy;
- the distribution was supposed to happen in Europe;
- the EoL was assumed in Europe.

Capital goods (land, buildings, machinery), and packaging, (except those of the finished product) were excluded from the analysis, by performing a cut-off according to the rules established in the ISO standards (data less than 1%, processes, input and/or output not relevant for the calculation).

The impact categories and evaluation methods are those defined in the Guideline for the implementation of the European Product Environmental Footprint PEF (EC 2016); the long-term emissions were not included (Table 1). No allocation procedures were performed, since there are not secondary products. Due to a part of tissue is discarded at the end of the weaving stage, this was treated as scrap, and thus considered as totally recycled. GaBi software and its datasets were employed to model the whole life cycle (IKP and PE 2002).

2.2 Life Cycle Inventory and Data Quality

According to the LCA methodology, for each phase of the life cycle studied, the material and energy flows, as well as the emissions in air, soil and water were quantified and referred to a kg of 100% PET fabric for mattress covering.

Table 2 shows data sources for the main input and output considered in the various phases of the life cycle. Data were principally collected directly by involving companies and experts of the sector, in particular active data derive from observations and interviewing of technicians carried out on site.

Data of energy mixes were obtained from GaBi and Plastics Europe database. On the contrary data of the Chinese mix, were taken from industry experts, and literature (Cui and Hong Gao 2012, Hasanbeigi et al. 2012, Wang et al. 2014).

All the transports of raw materials were considered. The means of transport are truck and ship, and the distance between the place of production and place of use was considered. The distribution was assumed in Europe, by considering an average distance of 1,200 km (50% ship and trucks 50%). As for the EoL, an average distance of 300 km was assumed for product disposing 50% in landfill and 50% by using an incinerator for energy recovery. In this latter case, co-generation was considered, in order to obtain heat and electricity. According to the GaBi dataset, a net calorific value of 22.2 MJ/kg was considered in PET incineration. This allow to obtain about 2 kWh of electricity and over 20 MJ of heat per kg of fabric.

The recovering of PET feedstock energy represents an 'avoided impact' (Guinée et al. 2001, EPA 2006, EC 2016) referred to the production of electricity (Italian grid mix) and thermal energy from methane.

The quality of data was calculated according to the Data Quality Rating (DQR) indicated in the guidelines for PEF implementation. Six criteria were considered in the semi-quantitative assessment of overall data quality of the Life Cycle Inventory datasets used in the study: technology representativeness (TEC), geographical representativeness (GEO), time representativeness (TIM), completeness (COM), parameter uncertainty (UNC) and Methodological appropriateness and consistency (MET). Table 3 shows the single score for each stage of the LCI (mean of score for all criteria) and the overall score as mean of the single scores.

3 Results

3.1 LCI results

Fig. 2 shows the emissions, defined in the EU Ecolabel criteria for textiles, extrapolated from the inventory data. The amount of water used is higher in the process of PET yarn dyeing (69.6%) due to the large amount of water used for the washing steps (EPA 1997, Laursen et al. 2007). Most of the CO2 comes from PET yarn production (60.5%). These processes have a high expenditure of energy, also the electricity mix of China is very rich in coal and this worsen considerably its environmental burden (Das 2011, Chang et al. 2012, Cui and Hong Gao 2012).

Formaldehyde is known to be a typical emission of the processes of dyeing and finishing, as the results confirm (58.8% PET yarn dyeing process, 40.1% PET fiber finishing process) (IPPC 2003b). VOCs are most frequent in PET yarn production process (90.1%) respect to the other phases.

3.2 LCIA results

Fig. 3 shows the results, in percentage, of the seventeen impact categories defined in the PEF guidelines. The PET yarn production brings about great contribution in almost all the categories (GWPt, GWPf, GWPb, HTc HTnc, A, PM, E, Ir, POF, TE, RD). This is due to the China electricity mix, which includes hard coal burning. The category OD is most affected from the production of polypropylene fibers used in the phase of fabric finishing. As concerns the category FE, the disposing in landfill of the fabric is the most pollutant phase, while the transportation phase entails highest contribution in the category ME. The category LU is principally affected by the Italian production of electricity from natural gas (used for fabric production). The use of electricity influences also the category RDw. In this case, the PET granulates for yarn production and the use of tap water in the phase of dyeing contribute to rise up the impacts.

3.3 Scenario analysis

Due to the data uncertainty and system variability in LCA, sensitivity analysis is often adopted to identify how results vary as a consequence of a change in the model input values (Bisinella et al. 2016).

According to the results highlighted in the impact assessment, a scenario analysis was carried out, by taking into account possible hypothesis of PET yarn supplying and final disposing of PET fabric.

In particular, the production of PET yarn is an important hotspot, so alternative scenarios of yarn supply were investigated, taking into account hypothesis in which the real economic convenience to buy the yarn from other non-Chinese producers could meet an environmental convenience, too.

Turkey, Slovakia and Italy are respectively the countries in which the buying of polyester yarn could be convenient from an economic point of view. The electricity grid mix and transportation were the input taken into account for the comparison. Furthermore, two other EoL scenarios were evaluated: the disposal of 100% of the product in landfill and 100% incinerated for energy recovery.

Table 4 shows the results of the comparison by highlighting, for each impact category, the best of the five scenarios. By analysing the results in the table, it is not possible to indicate the best scenario in absolute: to reduce distance for yarn supplying it is surely a sustainable practice, despite to buy yarn in Italy respect to Slovakia doesn’t ever entail impacts reduction. To recover the product at EoL for energy, through incineration, represents a good way to improve the environmental performance in the overall life cycle. In this case, a particular attention should be addressed to control the emissions of the combustion, because this practice brings high environmental problems in terms of global warming.

3.4 Monte Carlo Analysis

A Monte Carlo simulation was performed to assess sensitivity of results related to data uncertainty. Table 5 shows the standard deviation of the input and output considered in the phases of the life cycle. Fig. 4 shows the Gaussian distribution for all the impact categories considered in the analysis. In particular, the impact categories, distributed from the 10% percentile up to the 90% percentile, that are mainly affected from the data variability (expressed by the standard deviation in Table 5) are GWPt, GWPf, A, TE, PM, POF.

4 Conclusions

Descending from the previous outcomes, the life cycle processes most susceptible of improvements resulted to be: the PET yarns production (the more impactful phase), the EoL phase, the dyeing yarn and the finishing fabric processes. The scenario analysis conducted (by assuming alternative suppliers of PET) show that there is no significant improvement either by changing the transport strategy or by reducing the distance (reduction of fossil fuel use and the related emissions). This is due to the energy mix of the supplier countries, which consists largely on fossil resources and provides the greatest contribution to each impact category considered.

Alternative scenarios of EoL shown that the environmental performance of the product improves recovering energy and heat (incineration of the product). The dyeing yarn processes and finishing should thus be optimized, using the best available techniques for reducing the amount of water and formaldehyde.

As a conclusion, the company may pursue a number of improvements, including the use of recycled PET, to reach a sustainable product. Still the main environmental problem remains unsolved caused by the large use of fossil fuels.

Finally, the results show that policy makers and industry associations can develop a road map for sustainable textile industry, including policies for recycling.

Suggestions for the next steps are to perform a deeper study on recycling PET as well as to develop alternative a more sustainable fibers and yarns, such as those obtained from the scraps of other production sectors such as corn, sugar (molasses) and milk (whey).

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Author contribution Giuseppe Martino Nicoletti and designed the research; Carlo Russo and Pasqua L’Abbate performed research and analysed data; Giulio Mario Cappelletti, Giuseppe Ioppolo and Michele Dassisti wrote the paper. All authors read and approved the final manuscript.

Conflict of Interest authors have no conflict of interest to declare.

References

Aizenshtein, E. M. 2010. Stills no crisis for polyester fibers. Fiber Chemistry **42**:1-9.

Apulia Stretch. 2015. Private Communication

Baumann, H., and A. M. Tillman. 2004. The hitchhiker’s guide to LCA: an orientation in life cycle assessment methodology and application. Studentlitteratur, Lund, Sweden.

Bisinella, V., K. Conradsen, T. H. Christensen, and T. F. Astrup. 2016. A global approach for sparse representation of uncertainty in Life Cycle Assessments of waste management systems. The International Journal of Life Cycle Assessment **21**:378-394.

Chang, A., K. Pashikanti, and Y. A. Liu. 2012. Refinery Engineering: Integrated Process Modeling and Optimization. Wiley-VCH Verlag Gmbh, Weinheim.

Cui, X. J., and M. Hong Gao. 2012. Environmental impact assessment of three coal-based electricity generation scenarios in China. Energy **45**:952-959.

Dahllöf, L. 2004. LCA methodology issues for textile products. Technical report no. 2004:8. Licentiate thesis. Chalmers University of Technology.

Das, S. 2011. Life cycle assessment of carbon fiber polymer. International Journal of life Cycle Assessment **16**:268-282.

De Saxce, M., S. Pesnel, and A. L. Perwuelz. 2012. LCA of bed sheets e some relevant parameters for lifetime assessment. Journal of Cleaner Production **37**:221-228.

Deliege, E. J. M., and D. S. C. Nijdam. 1998. European ECOlabel Bed Mattresses. LCA and criteria proposals final report for the EC. Report number: R3535924.W05/EJD.

EC. 2004. Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions

Textiles and Clothing after 2005 – Recommendations of the High Level Group for Textiles and Clothing, COM(2004) 668. Brussels.

EC. 2008. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, "Public Procurement for a Better Environment".

EC. 2009. COMMISSION DECISION of 9 July 2009. Establishing the ecological criteria for the award of the Community Ecolabel for bed mattresses.

EC. 2010a. Environmental Improvement Potential of Textiles (IMPRO- Textiles), JRC Scientific and Technical Reports.

EC. 2010b. International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Joint Research Centre - Institute for Environment and Sustainability, EUR 24708 EN. Publications Office of the European Union, Luxembourg.

EC. 2010c. Regulation (EC) No 66/2010 of the Parliament and of the Council of 25 November 2009 on the EU Ecolabel.

EC. 2012. Revision of the European Ecolabel and Green Public Procurement (GPP) Criteria for Textile Products, JRC Technical Report.

EC. 2016. Guidance for the implementation of the EU Product Environmental Footprint (PEF) during the Environmental Footprint (EF) Pilot Phase, Guidance for the implementation of the EU PEF during the EF pilot phase - Version 5.2 - February 2016.

EPA. 1997. Profile of the textile industry (EPA/310-R-97-009), . Environmental Protection Agency, Washington DC.

EPA. 2006. Regulatory Impact Analysis, 2006 National Ambient Air Quality Standards for Particle Pollution, Chapter 5.

EU. 2014. Establishing the ecological criteria for the award of the EU Ecolabel for textile products (notified under document C (2014) 3677) (Text with EEA relevance) (2014/350/EU) Commission Decision of 5 June 2014.

EURATEX. 2012. Annual Report.

EURATEX. 2014. Annual Report.

EURATEX. 2015a. Annual Report.

EURATEX. 2015b. Keyfigures.

Guinée, J. B., M. Gorée, R. Heijungs, G. Huppes, R. Kleijn, A. D. Koning, L. V. Oers, Wegener, A. Sleeswijk, S. Suh, H. A. Udo de Haes, H. d. Bruijn, R. v. Duin, and M. A. J. Huijbregts. 2001. Handbook on Life Cycle Assessment - Operational Guide to the ISO Standards. . Kluwer Academic Publishers, Dordrecht.

Hasanbeigi, A., A. Hasanabadi, and M. Abdorrazaghi. 2012. Comparison analysis of energy intensity for five major sub-sectors of the Textile Industry in Iran Journal of Cleaner Production **23**:186-194.

IKP and PE. 2002. GaBi 4 - Software-system and databases for life cycle engineering, Stuttgart, Echterdingen.

IPPC. 2003a. Integrated Pollution Prevention and Control, Reference Document on Best Available Techniques for the Textiles Industry.

IPPC. 2003b. Integrated Pollution Prevention and Control. Reference Document on Best Available Techniques in the Large Volume Organic Chemical Industry February 2003.

ISO 14040. 2006. Environmental management - Life cycle assessment - Principles and framework ISO 14040:2006. International Standard Organization, Geneva.

ISO 14044. 2006. Environmental management - Life cycle assessment - Requirements and guidelines. ISO 14044:2006. International Standard Organization, Geneva.

JRC. 2013. Joint Research Centre, Directorate B - Growth and Innovation. EU Ecolabel and Green Public Procurement for Textiles.

Koç, E., and E. Çinçik. 2010. Analysis of Energy Consumption in Woven Fabric Production. FIBRES & TEXTILES in Eastern Europe **18**:14-20.

Lanoë, T., C. L. Simões, and R. Simoes. 2013. Improving the environmental performance of bedding products by using life cycle assessment at the design stage. Journal of Cleaner Production **52**:155-164.

Laursen, S. A., J. Hansen, H. H. Knudsen, H. Wenzel, H. F. Larsen, and F. M. Kristensen. 2007. EDIPTEX – Environmental assessment of textiles, Working Report No. 24, Danish Environmental Protection Agency.

Nieminen-Kalliala, E. 2003. Environmental indicators of textile products for ISO (Type III) environmental product declaration. AUTEX Research Journal **4**:206-218.

Russell, A., T. Ekvall, and H. Baumann. 2005. Life cycle assessment – introduction and overview. Journal of Cleaner Production **13**:1207-1210.

Steinberger, J. K. D. F., O. Jolliet, and S. Erkman. 2009. A spatially explicit life cycle inventory of the global textile chain. International Journal of life Cycle Assessment **14**:443-455.

van der Velden, N. M., M. K. Patel, and J. G. Vogtländer. 2013. LCA benchmarking study on textiles made of cotton, polyester, nylon, acryl, or elastane. International Journal of life Cycle Assessment **19**:331-356.

Wang, X. Y., P. Chen, W. Sui, F. Gao, X. Qin, J. Wu, and J. Xiong. 2014. Efficiency and sustainability analysis of biogas and electricity production from a large-scale biogas project in China: an emergy evaluation based on LCA, . Journal of Cleaner Production **65**:234-235.

Tables

Table 1 Impact categories.

Impact Category	Unit	Acronym
Climate change midpoint, excl. biogenic carbon (v1.06)	kg CO_2-eq	GWPf
Climate change midpoint, incl. biogenic carbon (v1.06)	kg CO_2-eq	GWPt = GWPf + GWPb
PEF-IPCC global warming (biogenic)	kg CO_2-eq	GWPb
Ozone depletion, WMO model, ReCiPe	kg CFC_{-11}-eq	OD
Human toxicity cancer effects, USEtox (without long-term)	CTUh	HTc
Human toxicity non-canc. effects, USEtox (without long-term)	CTUh	HTnc

Acidification, accumulated exceedance	Mole of H^{+}-eq	A
Particulate matter/Respiratory inorganics, RiskPoll	kg $PM_{2.5}$-eq	PM
Ecotoxicity for aquatic fresh water, USEtox (without long-term)	CTUe	E
Ionising radiation, human health effect model, ReCiPe (corrected)	kg ^{235}U-eq	Ir
Photochemical ozone formation, LOTOS-EUROS model, ReCiPe	kg NMVOC	POF
Terrestrial eutrophication, accumulated exceedance	Mole of N-eq	TE
Freshwater eutrophication, EUTREND model, ReCiPe (without long-term)	kg P-eq	FE
Marine eutrophication, EUTREND model, ReCiPe	kg N-eq	ME
Land use, Soil Organic Matter (SOM, Ecoinvent & Hemeroby—EMS—19 May 2015)	kg C deficit-eq	LU
Resource depletion water, midpoint, Swiss Ecoscarcity (v1.06—EMS—19 May 2015)	m³-eq.	RDw
Resource depletion, mineral, fossils and renewables, midpoint (v1.06)	kg Sb-eq	RD

Source: European Commission, 2015. PEF: Product Environmental Footprint; IPCC: Integrated Pollution Prevention and Control; WMO: World Meteorological Organization; CTUh: Comparative Toxic Unit for human.

Table 2 Data sources of the main input and output considered for each phase of the life cycle.

Process	***Data source***
PET Yarn Production Polymerization Spinning Twisting Texturing	- China Company; Expert; - GaBi database; - Literature: (IPPC 2003a, EC 2004, Steinberger et al. 2009, Cui and Hong Gao 2012, De Saxce et al. 2012, Hasanbeigi et al. 2012, van der Velden et al. 2013, Wang et al. 2014).
PET Yarn Warping PET Yarn Dyeing Thermosol process	- North Italy Company; - Experts; - GaBi dataset; - Literature: (IPPC 2003a, Nieminen-Kalliala 2003, EC 2004, Steinberger et al. 2009, Koç and Çinçik 2010, Hasanbeigi et al. 2012, van der Velden et al. 2013)
PET Fabric Production Weaving PET Fabric Finishing PET Fabric Storage and Distribution PET Fabric EoL	- Apulia Stretch; - Experts; - GaBi database; - Literature: (IPPC 2003a, Nieminen-Kalliala 2003, EC 2004, Steinberger et al. 2009, Koç and Çinçik 2010, Hasanbeigi et al. 2012, van der Velden et al. 2013)

Table 3 Data Quality Rating.

	TEC	GEO	TIM	COM	UNC	MET	Score
a) Resin Fiber production;	3	2	2	3	3	3	2.67
b) Yarn production;	3	2	2	3	3	3	2.67
c) Warping and dyeing;	2	2	2	2	2	2	2.00
d) Weaving,	1	2	2	2	2	2	1.83
e) Finishing (laminating);	1	2	1	1	1	1	1.17

f) Packaging;	1	2	1	1	1	1	1.17
g) Distribution and use;	2	1	2	1	2	2	1.67
h) End of life.	3	2	2	3	3	3	2.67
Overall score							**1.98**

Table 4 LCIA comparison, by considering variation in the overall life cycle of PET yarn supplying and treatment of the PET fabric at the end of life.

Impact Category	*Base scenario: PET Yarn from China EOL 50% incineration 50% landfill*	*Scenario A: PET Yarn from Turkey EOL 50% incineration 50% landfill*	*Scenario B: PET Yarn from Slovakia EOL 50% incineration 50% landfill*	*Scenario C: PET Yarn from Italy EOL 50% incineration 50% landfill*	*Scenario D: PET Yarn from China EoL 100% incineration*	*Scenario E PET Yarn from China EoL 100% landfill*
GWPt	1.50E+01	1.12E+01	**8.95E+00**	1.12E+01	1.56E+01	1.43E+01
GWPf	1.50E+01	1.13E+01	**8.95E+00**	1.12E+01	1.56E+01	1.43E+01
GWPb	1.03E-03	-2.59E-02	-3.95E-03	-2.56E-02	2.43E-03	**-3.61E-04**
OD	1.23E-10	1.54E-10	1.61E-10	1.53E-10	**1.22E-10**	1.23E-10
HTc	2.38E-08	2.40E-08	2.38E-08	2.40E-08	**2.36E-08**	2.39E-08
HTnc	2.74E-06	2.77E-06	2.78E-06	2.76E-06	**2.71E-06**	2.76E-06
A	3.55E-02	2.71E-02	3.84E-02	**2.66E-02**	3.47E-02	3.63E-02
PM	2.15E-03	1.54E-03	3.00E-03	**1.53E-03**	2.00E-03	2.30E-03
E	6.01E-01	6.31E-01	6.65E-01	6.25E-01	**5.89E-01**	6.13E-01
Ir	6.68E-02	7.43E-02	1.29E+00	7.42E-02	**6.65E-02**	6.72E-02
POF	2.88E-02	2.19E-02	2.25E-02	**2.17E-02**	2.82E-02	2.95E-02
TE	9.42E-02	6.93E-02	**6.49E-02**	6.72E-02	9.25E-02	9.59E-02
FE	4.43E-05	5.10E-05	4.87E-05	5.07E-05	**1.54E-05**	7.33E-05
ME	8.62E-04	1.16E-03	1.20E-03	1.04E-03	**8.58E-04**	8.66E-04
LU	4.86E-01	8.94E-01	8.28E-01	8.67E-01	**4.64E-01**	5.08E-01
RDw	3.96E-02	6.86E-02	1.35E-01	6.86E-02	**3.83E-02**	4.09E-02
RD	4.55E-06	8.30E-06	6.98E-06	8.29E-06	**4.28E-06**	4.83E-06

Table 5 Standard deviation in Input and Output of the life cycle.

Phase	*Input/Output*	*Standard deviation*		*Reference*
PET Yarn Production	Electricity	-24%	47%	(Aizenshtein 2010, Cui and Hong Gao 2012, Hasanbeigi et al. 2012, Wang et al. 2014).
	VOC	-70%	100%	(IPPC 2003a, Steinberger et al. 2009, EC 2012, van der Velden et al. 2013, EU 2014).
PET Yarn Dyeing	Formaldehyde	-69%	107%	(IPPC 2003a, Steinberger et al.

				2009, EC 2012, van der Velden et al. 2013, EU 2014).
PET Fabric Finishing		-50%	150%	(IPPC 2003a, Steinberger et al. 2009, EC 2012, van der Velden et al. 2013, EU 2014).
PET Yarn Dyeing	Tap Water	-47%	48%	(IPPC 2003a, EC 2012, EU 2014).

Figure Captions

Fig. 1 Geographical context and transportation flows.

Fig. 2 Inventory results, elementary flows: Use of water, CO_2, Formaldehyde, VOCs.

Fig. 3 Impact assessment of the life cycle of PET fabric used as outer cover for mattresses.

Fig. 4 Monte Carlo Analysis.

Figures

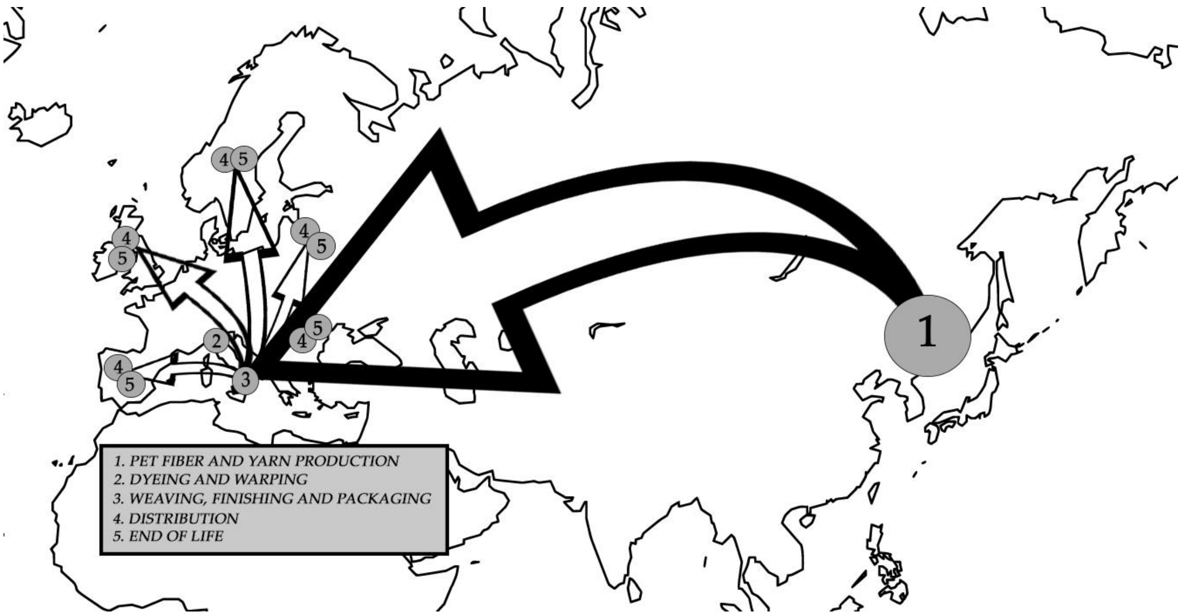

Fig. 1 Geographical context and transportation flows.

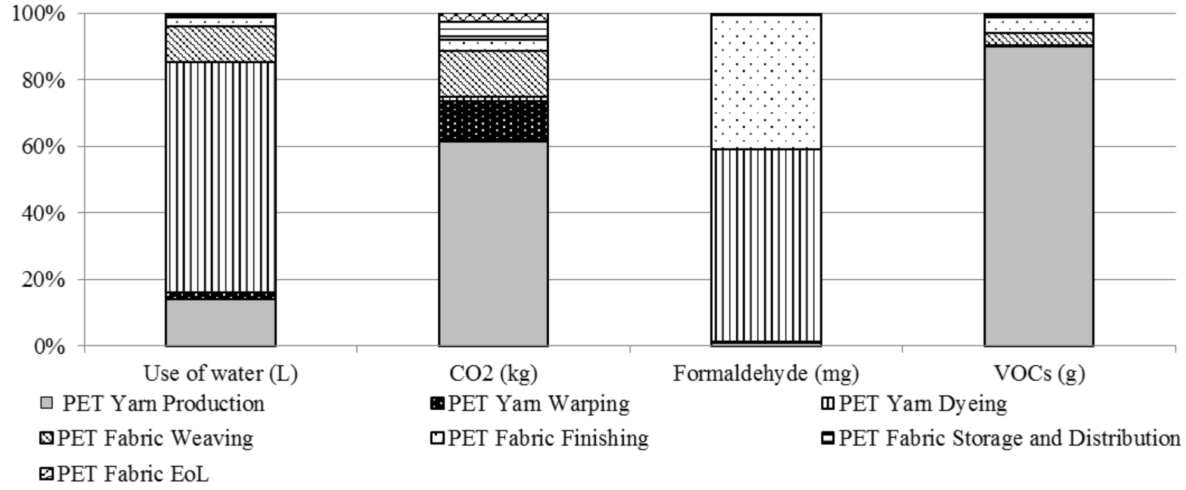

Fig. 2 Inventory results, elementary flows: Use of water, CO_2, Formaldehyde, VOCs.

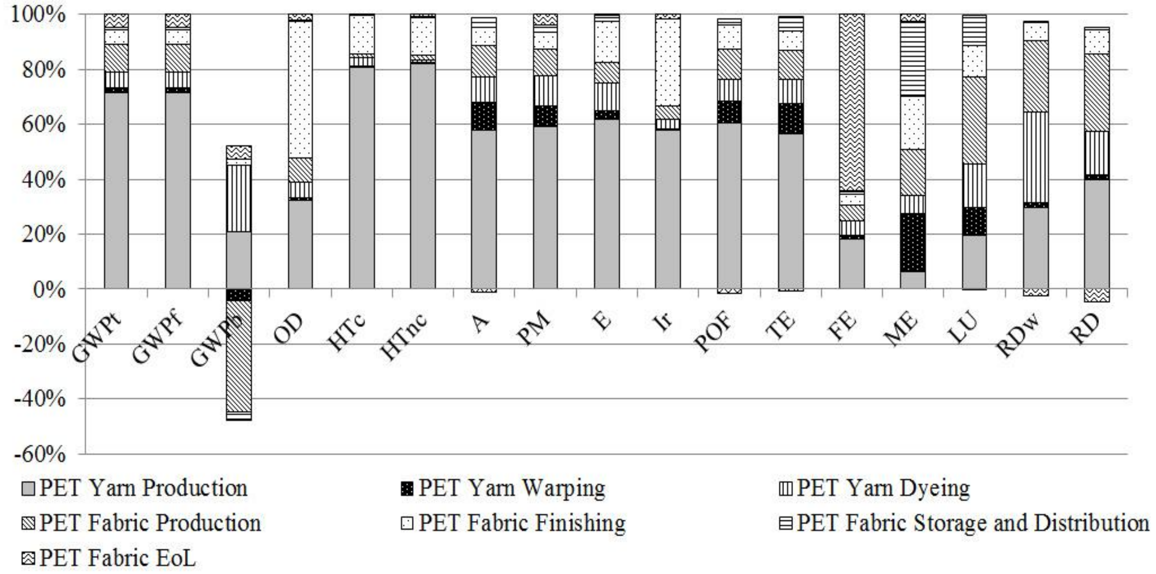

Fig. 3 Impact assessment of the life cycle of PET fabric used as outer cover for mattresses.

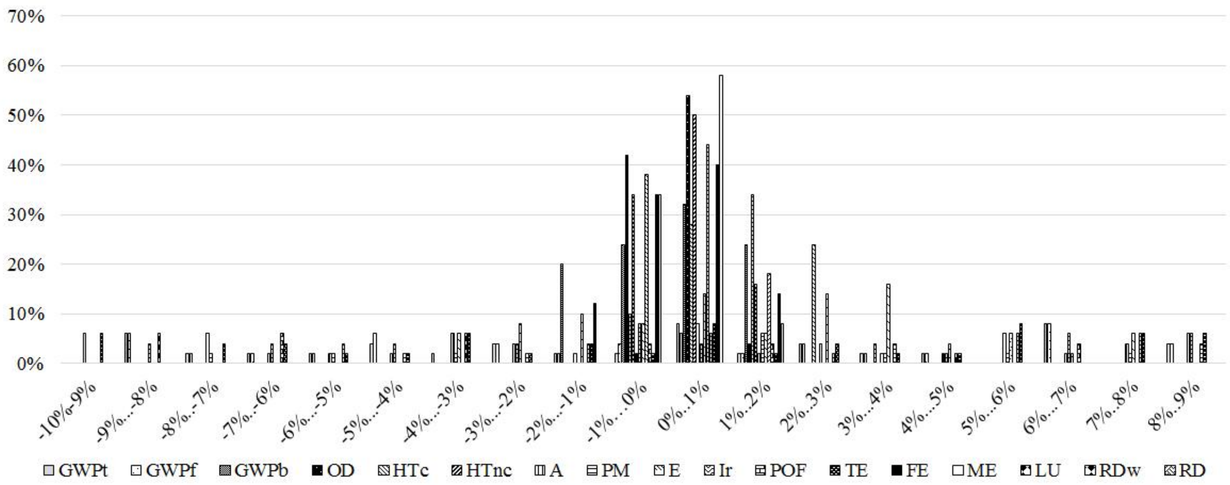

Fig. 4 Monte Carlo Analysis.

fig 1.jpg
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fig_2.jpg
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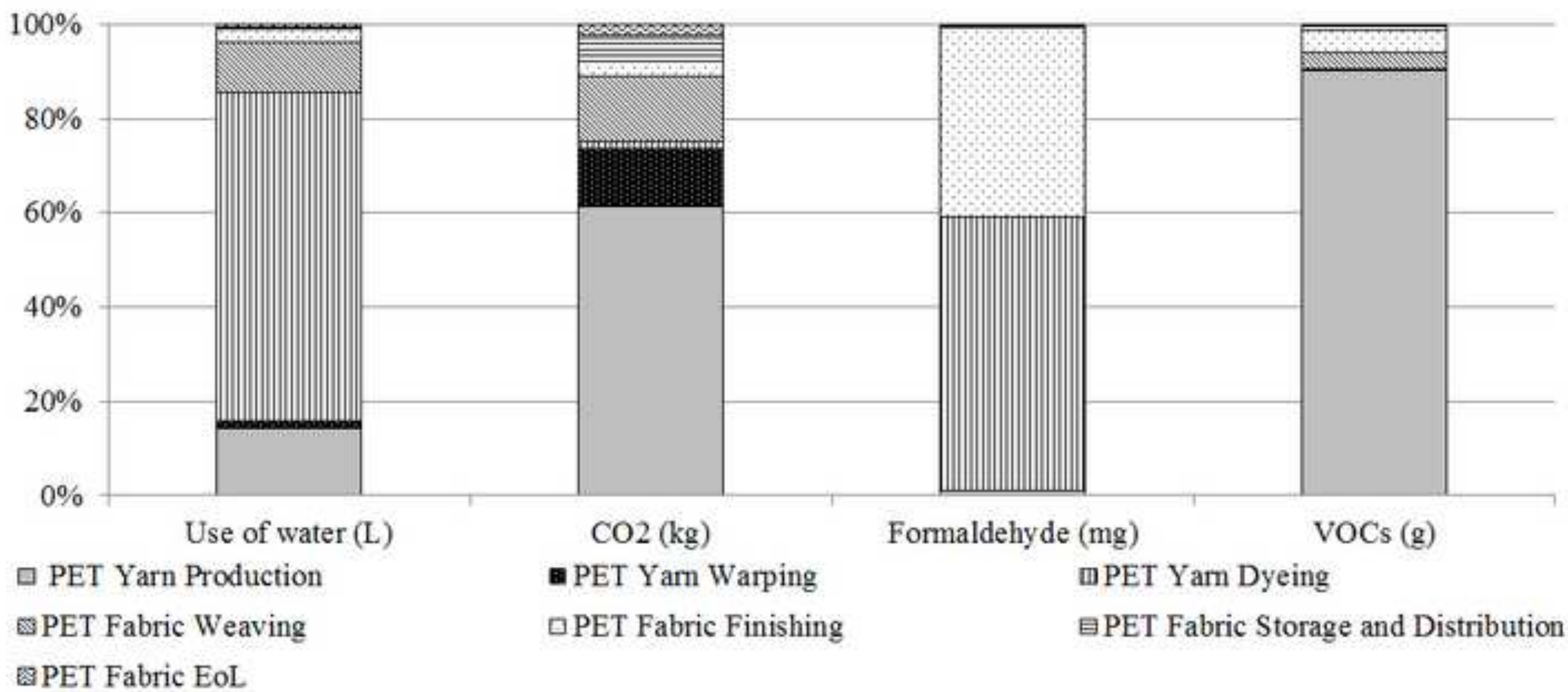

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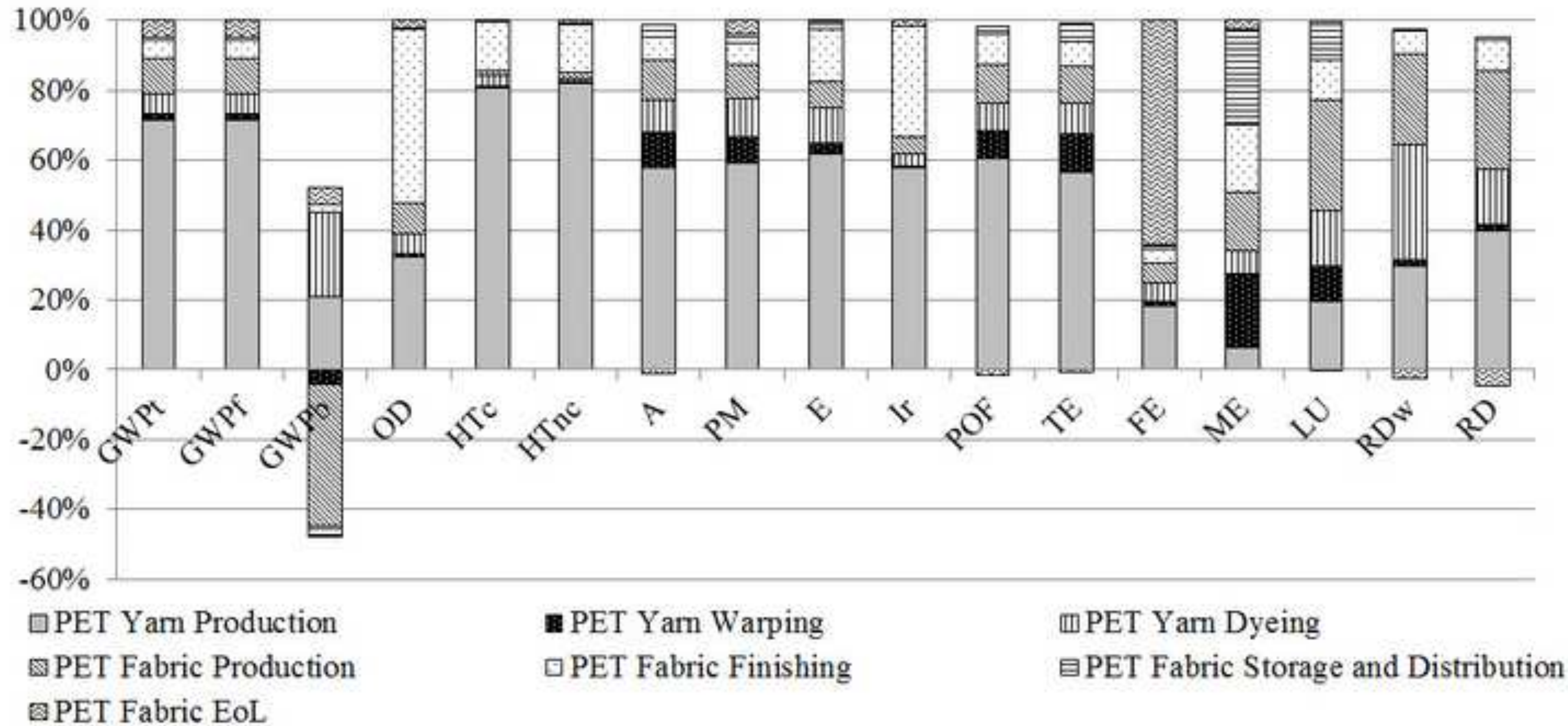

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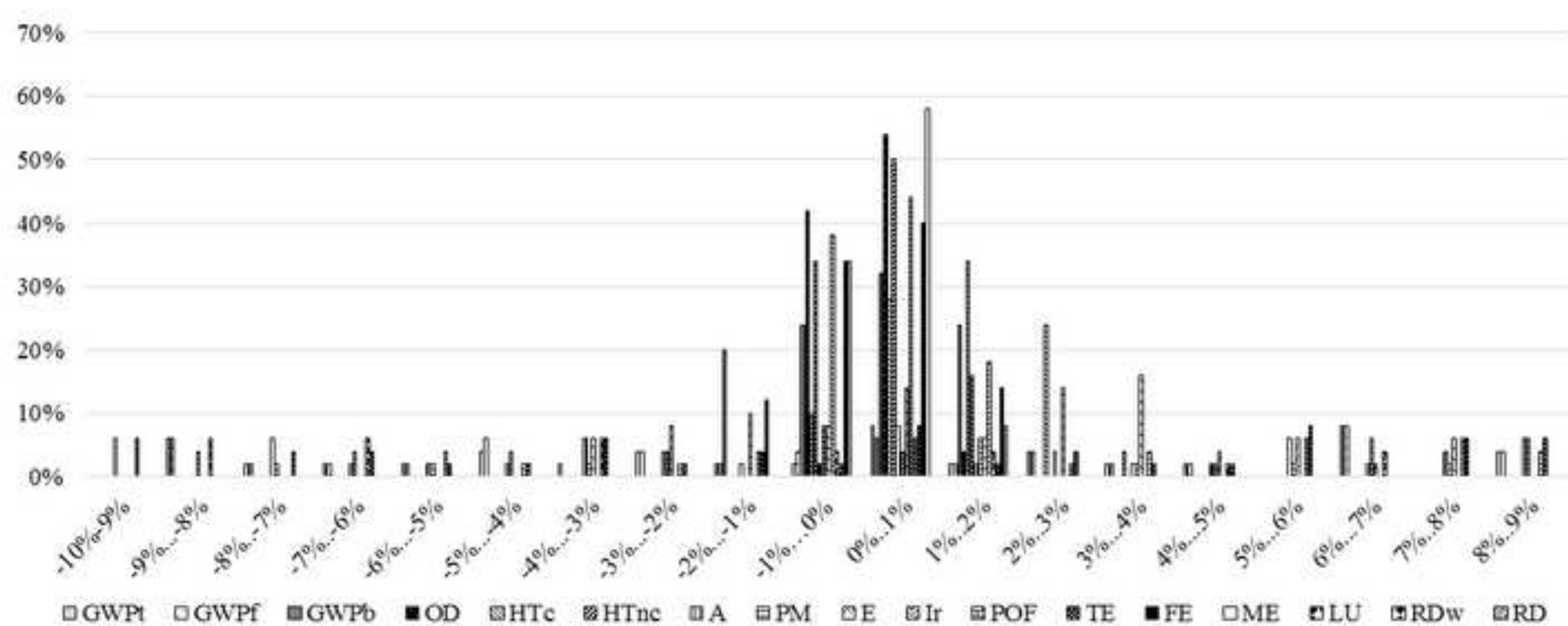

Dear Editor,

I am submitting the paper "**Environmental Analysis of Polyester Fabric for Ticking**" by L'Abbate et al. for a possible publication on the Special Volume of Journal Cleaner Production "VSI:Inn&Qual for sustainability".

In this manuscript, the principal issues of the process of ticking production were investigated in an environmental point of view. All authors mutually agree that this manuscript can be submitted to this journal. This manuscript has not already been published, or is not under consideration for publication elsewhere.

Please address all correspondence conceming this manuscript to pasqua.labbate@poliba.it

Looking forward to hearing from you,

Yours sincerely

Dr Pasqua L'Abbate

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Polytechnic of Bari,
4, Orabona Street,
Bari,70125,
Italy

Table 1

Table 1 Impact categories.

Impact Category	Unit	Acronym
Climate change midpoint, excl. biogenic carbon (v1.06)	kg CO_2-eq	GWPf
Climate change midpoint, incl. biogenic carbon (v1.06)	kg CO_2-eq	GWPt = GWPf + GWPb
PEF-IPCC global warming (biogenic)	kg CO_2-eq	GWPb
Ozone depletion, WMO model, ReCiPe	kg CFC-$_{11}$-eq	OD
Human toxicity cancer effects, USEtox (without long-term)	CTUh	HTc
Human toxicity non-canc. effects, USEtox (without long-term)	CTUh	HTnc
Acidification, accumulated exceedance	Mole of H^+-eq	A
Particulate matter/Respiratory inorganics, RiskPoll	kg $PM_{2.5}$-eq	PM
Ecotoxicity for aquatic fresh water, USEtox (without long-term)	CTUe	E
Ionising radiation, human health effect model, ReCiPe (corrected)	kg ^{235}U-eq	Ir
Photochemical ozone formation, LOTOS-EUROS model, ReCiPe	kg NMVOC	POF
Terrestrial eutrophication, accumulated exceedance	Mole of N-eq	TE
Freshwater eutrophication, EUTREND model, ReCiPe (without long-term)	kg P-eq	FE
Marine eutrophication, EUTREND model, ReCiPe	kg N-eq	ME
Land use, Soil Organic Matter (SOM, Ecoinvent & Hemeroby—EMS—19 May 2015)	kg C deficit-eq	LU
Resource depletion water, midpoint, Swiss Ecoscarcity (v1.06—EMS—19 May 2015)	m^3-eq.	RDw
Resource depletion, mineral, fossils and renewables, midpoint (v1.06)	kg Sb-eq	RD

Source: European Commission, 2015. PEF: Product Environmental Footprint; IPCC: Integrated Pollution Prevention and Control; WMO: World Meteorological Organization; CTUh: Comparative Toxic Unit for human.

Table 2

Table 2 Data sources of the main input and output considered for each phase of the life cycle.

Process	***Data source***
PET Yarn Production Polymerization Spinning Twisting Texturing	- China Company; Expert; - GaBi database; - Literature: (IPPC 2003a, EC 2004, Steinberger et al. 2009, Cui and Hong Gao 2012, De Saxce et al. 2012, Hasanbeigi et al. 2012, van der Velden et al. 2013, Wang et al. 2014).
PET Yarn Warping PET Yarn Dyeing Thermosol process	- North Italy Company; - Experts; - GaBi dataset; - Literature: (IPPC 2003a, Nieminen-Kalliala 2003, EC 2004, Steinberger et al. 2009, Koç and Çinçik 2010, Hasanbeigi et al. 2012, van der Velden et al. 2013)
PET Fabric Production Weaving PET Fabric Finishing PET Fabric Storage and Distribution PET Fabric EoL	- Apulia Stretch; - Experts; - GaBi database; - Literature: (IPPC 2003a, Nieminen-Kalliala 2003, EC 2004, Steinberger et al. 2009, Koç and Çinçik 2010, Hasanbeigi et al. 2012, van der Velden et al. 2013)

Table 3

Table 3 Data Quality Rating.

	TEC	GEO	TIM	COM	UNC	MET	Score
a) Resin Fiber production;	3	2	2	3	3	3	2.67
b) Yarn production;	3	2	2	3	3	3	2.67
c) Warping and dyeing;	2	2	2	2	2	2	2.00
d) Weaving,	1	2	2	2	2	2	1.83
e) Finishing (laminating);	1	2	1	1	1	1	1.17
f) Packaging;	1	2	1	1	1	1	1.17
g) Distribution and use;	2	1	2	1	2	2	1.67
h) End of life.	3	2	2	3	3	3	2.67
Overall score							**1.98**

Table 4

Table 4 LCIA comparison, by considering variation in the overall life cycle of PET yarn supplying and treatment of the PET fabric at the end of life.

Impact Category	***Base scenario: PET Yarn from China EOL 50% incineration 50% landfill***	***Scenario A: PET Yarn from Turkey EOL 50% incineration 50% landfill***	***Scenario B: PET Yarn from Slovakia EOL 50% incineration 50% landfill***	***Scenario C: PET Yarn from Italy EOL 50% incineration 50% landfill***	***Scenario D: PET Yarn from China EoL 100% incineration***	***Scenario E PET Yarn from China EoL 100% landfill***
GWPt	1.50E+01	1.12E+01	**8.95E+00**	1.12E+01	1.56E+01	1.43E+01
GWPf	1.50E+01	1.13E+01	**8.95E+00**	1.12E+01	1.56E+01	1.43E+01
GWPb	1.03E-03	-2.59E-02	-3.95E-03	-2.56E-02	2.43E-03	**-3.61E-04**
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