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Environmental Analysis of Polyester Fabric for Ticking

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Corresponding Author: Dr. Pasqua L'Abbate,

Corresponding Author's Institution: Polytechnic of Bari

First Author: Pasqua L'Abbate

Order of Authors: Pasqua L'Abbate; Carlo Russo, Ph.D; Michele D'assisti; Giulio Mario Cappelletti; Giuseppe Martino Nicoletti; Ioppolo Guseppe

Abstract: Purpose: This study aims to analyse the environmental performances of the life cycle of a 100% PET fabric used for outer cover of bed mattresses (ticking), made by an Italian company.

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.

Suggested Reviewers: Alberto Simboli
alberto.simboli@unich.it

Marzia Traverso
Marziatraverso@gmail.com

Alessio Tola
tola@uniss.it

Bruno Notarnicola
bruno.notarnicola@uniba.it

Environmental Analysis of Polyester Fabric for Ticking

Pasqua L'Abbate^{1*}, Michele Dassisi², Giulio Mario Cappelletti³, Giuseppe Martino Nicoletti³, Carlo Russo³, Giuseppe Ioppolo⁴

¹ Department of Civil, Environmental, Building Engineering and Chemistry, Polytechnic of Bari, 4, Orabona Street, Bari, 70125, Italy

² Department of Mathematics, Mechanics and Management, Polytechnic of Bari, 182, Japigia Street, Bari, 70126, Italy

³ Department of Economics, University of Foggia, 1, Caggese R. Street, Foggia, 71121, Italy

⁴ Department of Economics, University of Messina, 1 Pugliatti Square, Messina, 98122, Italy

* Corresponding author: pasqua.labbate@poliba.it; Phone: +39 080 5963572;

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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.

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

1 relocation of production to the benefit of countries like Bulgaria and Romania, in a time when the euro showed
2 a significant upward trend against the US dollar (EURATEX 2012).

3 Studies of European Apparel and Textile Confederation (EURATEX) with the Saxion Universities for the
4 European Commission Enterprise and Industry, foresee that the textile industry, in Europe, will suffer a further
5 drop, following the relocation of the production of large enterprises to the Asian region, in growing markets,
6 due to trade barriers and difficulties to credit access for export and insurances of the enterprises. The European
7 textile industry consists mostly of SMEs. They still have a great resilience and are trying to restructure and
8 modernize, with the use of new green technologies and eco innovations, so they can adapt to changing market
9 conditions and be competitive (EURATEX 2014). So, in order to enhance competitiveness, textile companies
10 should pay particular attention to environmental issue and sustainable productions. The establishment of EU
11 Ecolabel and Green Public Procurement (GPP) criteria represents an opportunity for textile companies that
12 want differentiate their production by enhancing environmental, safety, technical and functional aspects (EC
13 2008, 2010c).

14 This paper aims to investigate the environmental impacts of a polyester fabric used as mattresses outer
15 cover also called “tick” or “ticking” (Deliege and Nijdam 1998), by adopting the Life Cycle Assessment (LCA)
16 methodology (Guinée et al. 2001, Baumann and Tillman 2004, Russell et al. 2005, EC 2010b). The paper also
17 focused on some environmental issues identified within the EU Ecolabel scheme for bed mattresses (EC 2009)
18 which are compliant with the criteria of the EU Ecolabel for textiles (Steinberger et al. 2009, EC 2012, JRC
19 2013, van der Velden et al. 2013).

20 To the knowledge of authors, there are no specific studies on the type of product analysed. A series of
21 studies on tissues obtained from the raw material PET and other types of yarns were taken as references, having
22 either the weaving process similar to that studied (Nieminen-Kalliala 2003, Dahllöf 2004, Steinberger et al.
23 2009, Koç and Çinçik 2010, De Saxce et al. 2012, Hasanbeigi et al. 2012, Lanoë et al. 2013, van der Velden et
24 al. 2013) or those treating the European Ecolabel Bed Mattresses, LCA and criteria proposals final report for the
25 EC (Deliege and Nijdam 1998).

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

28 **2 Materials and Methods**

29 *2.1 LCA of a PET outer cover for bed mattresses*

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

36 As for goal and scope, the functional unit (FU) was 1 kg of 100% PET ticking, obtained using a Jacquard
37 frame, and further laminated to a non-woven polypropylene (PP). The lifetime was assumed for 10 years (IPPC
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1 2003a). As the cover of mattresses is not washable (no maintenance is made if not dusted or mechanically
 2 beaten), in the use phase no emissions were observed. For the end of life (EoL), the hypothesis of 50% disposed
 3 in landfills and 50% incinerated was assumed. As concerns the system boundaries, the life cycle was considered
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 7 “form cradle to grave”. The following stage were thus included:

- 8
- 9 a) resin fiber production (polymerization);
- 10
- 11 b) yarn production (spinning-twisting-texturing);
- 12
- 13 c) processes of weaving preparation: warping and dyeing;
- 14
- 15 d) weaving,
- 16
- 17 e) finishing (laminating);
- 18
- 19 f) packaging,
- 20
- 21 g) distribution and use;
- 22
- 23 h) end of life.
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26 As concerns the geographical context the following hypothesis were considered according to the situation
 27 concerning the company involved in the study (Fig. 1) (Apulia Stretch 2015):

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- 29
- 30 - fiber and polyester yarn were produced in China;
- 31
- 32 - the preparation of the yarn for weaving and the steps of dyeing and warping were carried out in
- 33
- 34

35 Northern Italy;

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- 37 - the steps of weaving, finishing, packaging were carried out in Southern Italy;
- 38
- 39 - the distribution was supposed to happen in Europe;
- 40
- 41 - the EoL was assumed in Europe.
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44 Capital goods (land, buildings, machinery), and packaging, (except those of the finished product) were
 45 excluded from the analysis, by performing a cut-off according to the rules established in the ISO standards (data
 46 less than 1%, processes, input and/or output not relevant for the calculation).
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48 The impact categories and evaluation methods are those defined in the Guideline for the implementation
 49 of the European Product Environmental Footprint PEF (EC 2016); the long-term emissions were not included
 50 (Table 1). No allocation procedures were performed, since there are not secondary products. Due to a part of
 51 tissue is discarded at the end of the weaving stage, this was treated as scrap, and thus considered as totally
 52 recycled. GaBi software and its datasets were employed to model the whole life cycle (IKP and PE 2002).
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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

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

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

10 3.2 LCIA results

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

20 3.3 Scenario analysis

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

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

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

28 Turkey, Slovakia and Italy are respectively the countries in which the buying of polyester yarn could be
29 convenient from an economic point of view. The electricity grid mix and transportation were the input taken
30

1 into account for the comparison. Furthermore, two other EoL scenarios were evaluated: the disposal of 100% of
2 the product in landfill and 100% incinerated for energy recovery.
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5 Table 4 shows the results of the comparison by highlighting, for each impact category, the best of the five
6 scenarios. By analysing the results in the table, it is not possible to indicate the best scenario in absolute: to
7 reduce distance for yarn supplying it is surely a sustainable practice, despite to buy yarn in Italy respect to
8 Slovakia doesn't ever entail impacts reduction. To recover the product at EoL for energy, through incineration,
9 represents a good way to improve the environmental performance in the overall life cycle. In this case, a
10 particular attention should be addressed to control the emissions of the combustion, because this practice brings
11 high environmental problems in terms of global warming.
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19 *3.4 Monte Carlo Analysis*

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22 A Monte Carlo simulation was performed to assess sensitivity of results related to data uncertainty. Table
23 5 shows the standard deviation of the input and output considered in the phases of the life cycle. Fig. 4 shows the
24 Gaussian distribution for all the impact categories considered in the analysis. In particular, the impact
25 categories, distributed from the 10% percentile up to the 90% percentile, that are mainly affected from the data
26 variability (expressed by the standard deviation in Table 5) are GWPt, GWPf, A, TE, PM, POF.
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33 **4 Conclusions**

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38 Descending from the previous outcomes, the life cycle processes most susceptible of improvements resulted to
39 be: the PET yarns production (the more impactful phase), the EoL phase, the dyeing yarn and the finishing
40 fabric processes. The scenario analysis conducted (by assuming alternative suppliers of PET) show that there is
41 no significant improvement either by changing the transport strategy or by reducing the distance (reduction of
42 fossil fuel use and the related emissions). This is due to the energy mix of the supplier countries, which consists
43 largely on fossil resources and provides the greatest contribution to each impact category considered.
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49 Alternative scenarios of EoL shown that the environmental performance of the product improves recovering
50 energy and heat (incineration of the product). The dyeing yarn processes and finishing should thus be
51 optimized, using the best available techniques for reducing the amount of water and formaldehyde.
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57 As a conclusion, the company may pursue a number of improvements, including the use of recycled PET, to
58 reach a sustainable product. Still the main environmental problem remains unsolved caused by the large use of
59 fossil fuels.
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1 Finally, the results show that policy makers and industry associations can develop a road map for sustainable
 2 textile industry, including policies for recycling.

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 4 Suggestions for the next steps are to perform a deeper study on recycling PET as well as to develop alternative
 5 a more sustainable fibers and yarns, such as those obtained from the scraps of other production sectors such as
 6 corn, sugar (molasses) and milk (whey).
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 15

16
 17 **Author contribution** Giuseppe Martino Nicoletti and designed the research; Carlo Russo and Pasqua L’Abbate
 18 performed research and analysed data; Giulio Mario Cappelletti, Giuseppe Ioppolo and Michele Dassisti wrote
 19 the paper. All authors read and approved the final manuscript.
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26 **Conflict of Interest** authors have no conflict of interest to declare.
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29 **References**

- 30 Aizenshtein, E. M. 2010. Stills no crisis for polyester fibers. *Fiber Chemistry* **42**:1-9.
 31 Apulia Stretch. 2015. Private Communication
 32 Baumann, H., and A. M. Tillman. 2004. The hitchhiker’s guide to LCA: an orientation in life
 33 cycle assessment methodology and application. Studentlitteratur, Lund, Sweden.
 34 Bisinella, V., K. Conradsen, T. H. Christensen, and T. F. Astrup. 2016. A global approach for
 35 sparse representation of uncertainty in Life Cycle Assessments of waste management
 36 systems. *The International Journal of Life Cycle Assessment* **21**:378-394.
 37 Chang, A., K. Pashikanti, and Y. A. Liu. 2012. *Refinery Engineering: Integrated Process
 38 Modeling and Optimization*. Wiley-VCH Verlag GmbH, Weinheim.
 39 Cui, X. J., and M. Hong Gao. 2012. Environmental impact assessment of three coal-based
 40 electricity generation scenarios in China. *Energy* **45**:952-959.
 41 Dahllöf, L. 2004. LCA methodology issues for textile products. Technical report no. 2004:8.
 42 Licentiate thesis. Chalmers University of Technology.
 43 Das, S. 2011. Life cycle assessment of carbon fiber polymer. *International Journal of life
 44 Cycle Assessment* **16**:268-282.
 45 De Saxce, M., S. Pesnel, and A. L. Perwuelz. 2012. LCA of bed sheets e some relevant
 46 parameters for lifetime assessment. *Journal of Cleaner Production* **37**:221-228.
 47 Deliege, E. J. M., and D. S. C. Nijdam. 1998. European ECOLabel Bed Mattresses. LCA and
 48 criteria proposals final report for the EC. Report number: R3535924.W05/EJD.
 49 EC. 2004. Communication from the Commission to the Council, the European Parliament,
 50 the European Economic and Social Committee and the Committee of the Regions
 51
 52
 53
 54
 55
 56
 57
 58
 59
 60
 61
 62
 63
 64
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1 Textiles and Clothing after 2005 – Recommendations of the High Level Group for
2 Textiles and Clothing, COM(2004) 668. Brussels.

3 EC. 2008. Communication from the Commission to the European Parliament, the Council,
4 the European Economic and Social Committee and the Committee of the Regions,
5 "Public Procurement for a Better Environment".
6

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

10 EC. 2010a. Environmental Improvement Potential of Textiles (IMPRO- Textiles), JRC
11 Scientific and Technical Reports.
12

13 EC. 2010b. International Reference Life Cycle Data System (ILCD) Handbook - General
14 guide for Life Cycle Assessment - Joint Research Centre - Institute for Environment
15 and Sustainability, EUR 24708 EN. Publications Office of the European Union,
16 Luxembourg.
17

18 EC. 2010c. Regulation (EC) No 66/2010 of the Parliament and of the Council of 25
19 November 2009 on the EU Ecolabel.
20

21 EC. 2012. Revision of the European Ecolabel and Green Public Procurement (GPP) Criteria
22 for Textile Products, JRC Technical Report.
23

24 EC. 2016. Guidance for the implementation of the EU Product Environmental Footprint
25 (PEF) during the Environmental Footprint (EF) Pilot Phase, Guidance for the
26 implementation of the EU PEF during the EF pilot phase - Version 5.2 - February
27 2016.
28

29 EPA. 1997. Profile of the textile industry (EPA/310-R-97-009), . Environmental Protection
30 Agency, Washington DC.
31

32 EPA. 2006. Regulatory Impact Analysis, 2006 National Ambient Air Quality Standards for
33 Particle Pollution, Chapter 5.
34

35 EU. 2014. Establishing the ecological criteria for the award of the EU Ecolabel for textile
36 products (notified under document C (2014) 3677) (Text with EEA relevance)
37 (2014/350/EU) Commission Decision of 5 June 2014.
38

39 EURATEX. 2012. Annual Report.
40

41 EURATEX. 2014. Annual Report.
42

43 EURATEX. 2015a. Annual Report.
44

45 EURATEX. 2015b. Keyfigures.
46

47 Guinée, J. B., M. Gorée, R. Heijungs, G. Huppes, R. Kleijn, A. D. Koning, L. V. Oers,
48 Wegener, A. Sleeswijk, S. Suh, H. A. Udo de Haes, H. d. Bruijn, R. v. Duin, and M.
49 A. J. Huijbregts. 2001. Handbook on Life Cycle Assessment - Operational Guide to
50 the ISO Standards. . Kluwer Academic Publishers, Dordrecht.
51

52 Hasanbeigi, A., A. Hasanabadi, and M. Abdorrazaghi. 2012. Comparison analysis of energy
53 intensity for five major sub-sectors of the Textile Industry in Iran Journal of Cleaner
54 Production **23**:186-194.
55

56 IKP and PE. 2002. GaBi 4 - Software-system and databases for life cycle engineering,
57 Stuttgart, Echterdingen.
58

59 IPPC. 2003a. Integrated Pollution Prevention and Control, Reference Document on Best
60 Available Techniques for the Textiles Industry.
61
62
63
64
65

- 1 IPCC. 2003b. Integrated Pollution Prevention and Control. Reference Document on Best
2 Available Techniques in the Large Volume Organic Chemical Industry February
3 2003.
- 4 ISO 14040. 2006. Environmental management - Life cycle assessment - Principles and
5 framework ISO 14040:2006. International Standard Organization, Geneva.
- 6 ISO 14044. 2006. Environmental management - Life cycle assessment - Requirements and
7 guidelines. ISO 14044:2006. International Standard Organization, Geneva.
- 8 JRC. 2013. Joint Research Centre, Directorate B - Growth and Innovation. EU Ecolabel and
9 Green Public Procurement for Textiles.
- 10 Koç, E., and E. Çinçik. 2010. Analysis of Energy Consumption in Woven Fabric Production.
11 FIBRES & TEXTILES in Eastern Europe **18**:14-20.
- 12 Lanoë, T., C. L. Simões, and R. Simoes. 2013. Improving the environmental performance of
13 bedding products by using life cycle assessment at the design stage. Journal of
14 Cleaner Production **52**:155-164.
- 15 Laursen, S. A., J. Hansen, H. H. Knudsen, H. Wenzel, H. F. Larsen, and F. M. Kristensen.
16 2007. EDIPTEx – Environmental assessment of textiles, Working Report No. 24,
17 Danish Environmental Protection Agency.
- 18 Nieminen-Kalliala, E. 2003. Environmental indicators of textile products for ISO (Type III)
19 environmental product declaration. AUTEX Research Journal **4**:206-218.
- 20 Russell, A., T. Ekvall, and H. Baumann. 2005. Life cycle assessment – introduction and
21 overview. Journal of Cleaner Production **13**:1207-1210.
- 22 Steinberger, J. K. D. F., O. Jolliet, and S. Erkman. 2009. A spatially explicit life cycle
23 inventory of the global textile chain. International Journal of life Cycle Assessment
24 **14**:443-455.
- 25 van der Velden, N. M., M. K. Patel, and J. G. Vogtländer. 2013. LCA benchmarking study on
26 textiles made of cotton, polyester, nylon, acryl, or elastane. International Journal of
27 life Cycle Assessment **19**:331-356.
- 28 Wang, X. Y., P. Chen, W. Sui, F. Gao, X. Qin, J. Wu, and J. Xiong. 2014. Efficiency and
29 sustainability analysis of biogas and electricity production from a large-scale biogas
30 project in China: an emergy evaluation based on LCA, . Journal of Cleaner
31 Production **65**:234-235.

47 Tables

50 **Table 1** Impact categories.

52 Impact Category	53 Unit	54 Acronym
55 Climate change midpoint, excl. biogenic carbon (v1.06)	56 kg CO ₂ -eq	57 GWPf
58 Climate change midpoint, incl. biogenic carbon (v1.06)	59 kg CO ₂ -eq	60 GWPt = GWPf + 61 GWPb
62 PEF-IPCC global warming (biogenic)	63 kg CO ₂ -eq	64 GWPb
65 Ozone depletion, WMO model, ReCiPe	66 kg 67 CFC-11-eq	68 OD
69 Human toxicity cancer effects, USEtox (without long-term)	70 CTUh	71 HTc
72 Human toxicity non-canc. effects, USEtox (without long-term)	73 CTUh	74 HTnc

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:		Scenario A:		Scenario B:		Scenario C:		Scenario D:		Scenario E:	
	PET Yarn from China	EOL 50% incineration	PET Yarn from Turkey	EOL 50% incineration	PET Yarn from Slovakia	EOL 50% incineration	PET Yarn from Italy	EOL 50% incineration	PET Yarn from China	EoL 100% incineration	PET Yarn from China	EoL 100% landfill
GWp _t	1.50E+01		1.12E+01		8.95E+00		1.12E+01		1.56E+01		1.43E+01	
GWp _f	1.50E+01		1.13E+01		8.95E+00		1.12E+01		1.56E+01		1.43E+01	
GWp _b	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	
HT _c	2.38E-08		2.40E-08		2.38E-08		2.40E-08		2.36E-08		2.39E-08	
HT _{nc}	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	
RD _w	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%
	VOC	-70%	100%
PET Yarn Dyeing	Formaldehyde	-69%	107%

				2009, EC 2012, van der Velden et al. 2013, EU 2014).
				(IPPC 2003a, Steinberger et al.
PET Fabric Finishing		-50%	150%	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, CO₂, 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

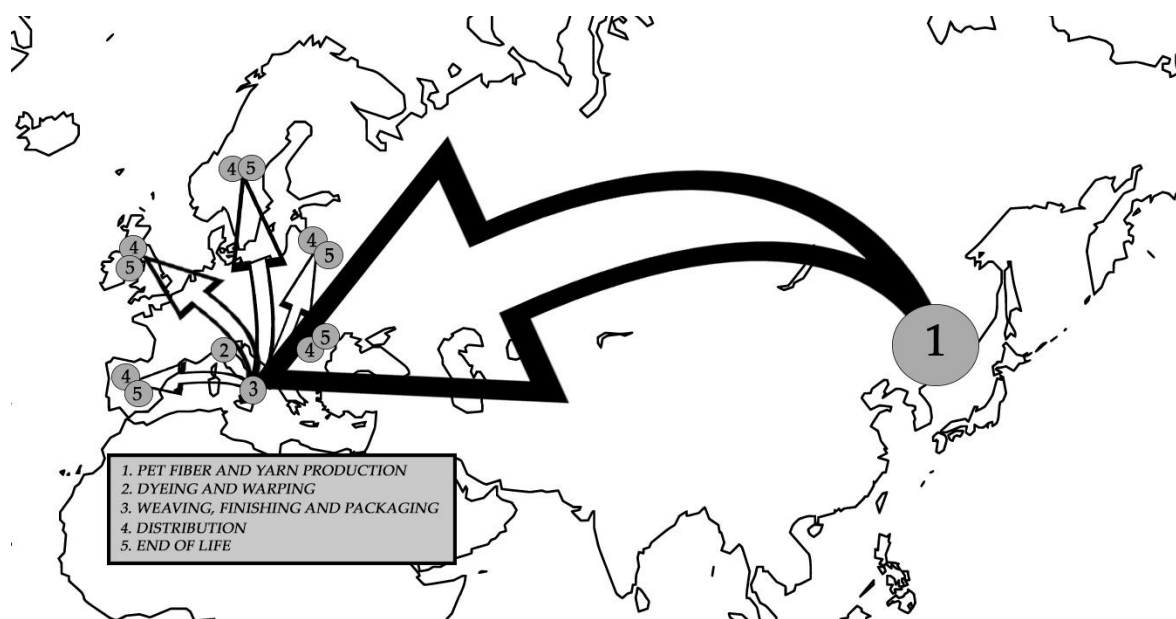


Fig. 1 Geographical context and transportation flows.

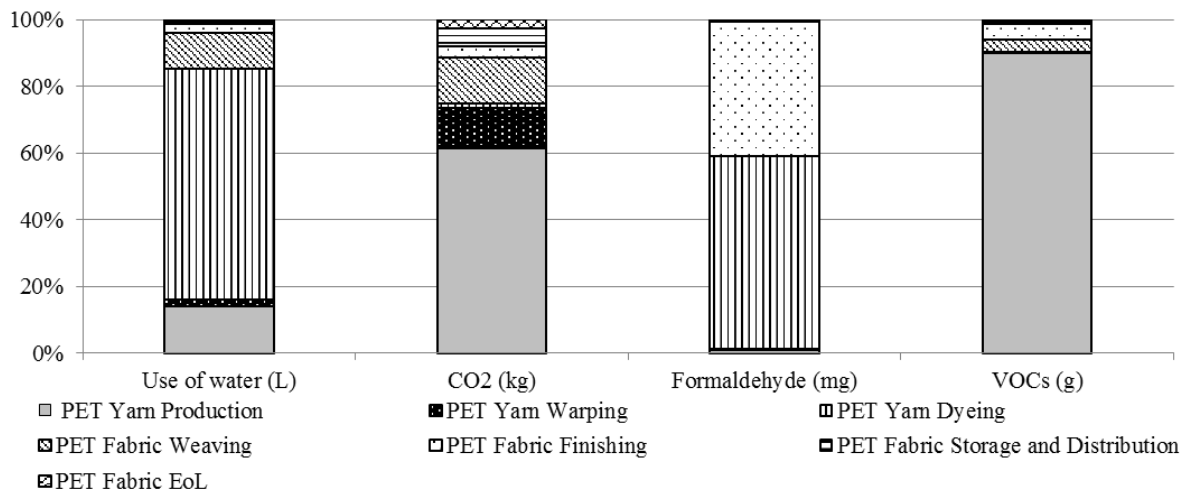


Fig. 2 Inventory results, elementary flows: Use of water, CO₂, Formaldehyde, VOCs.

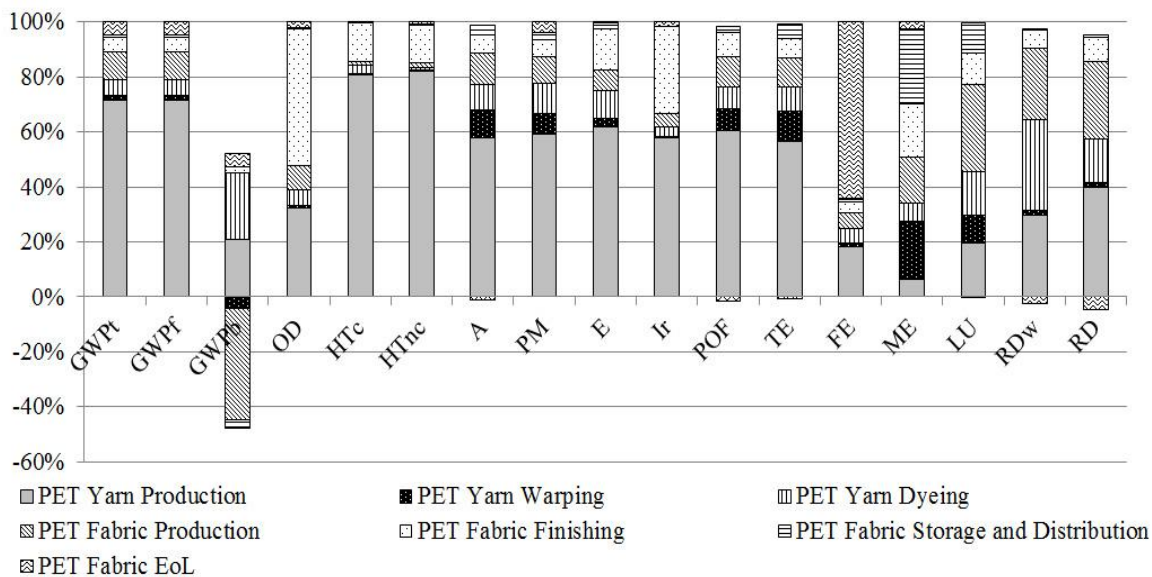


Fig. 3 Impact assessment of the life cycle of PET fabric used as outer cover for mattresses.

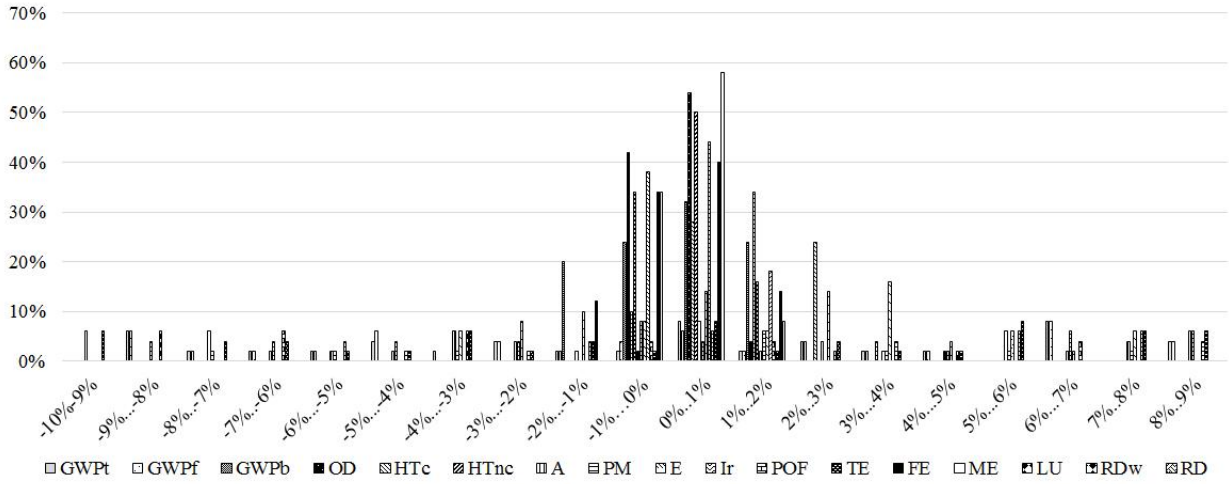
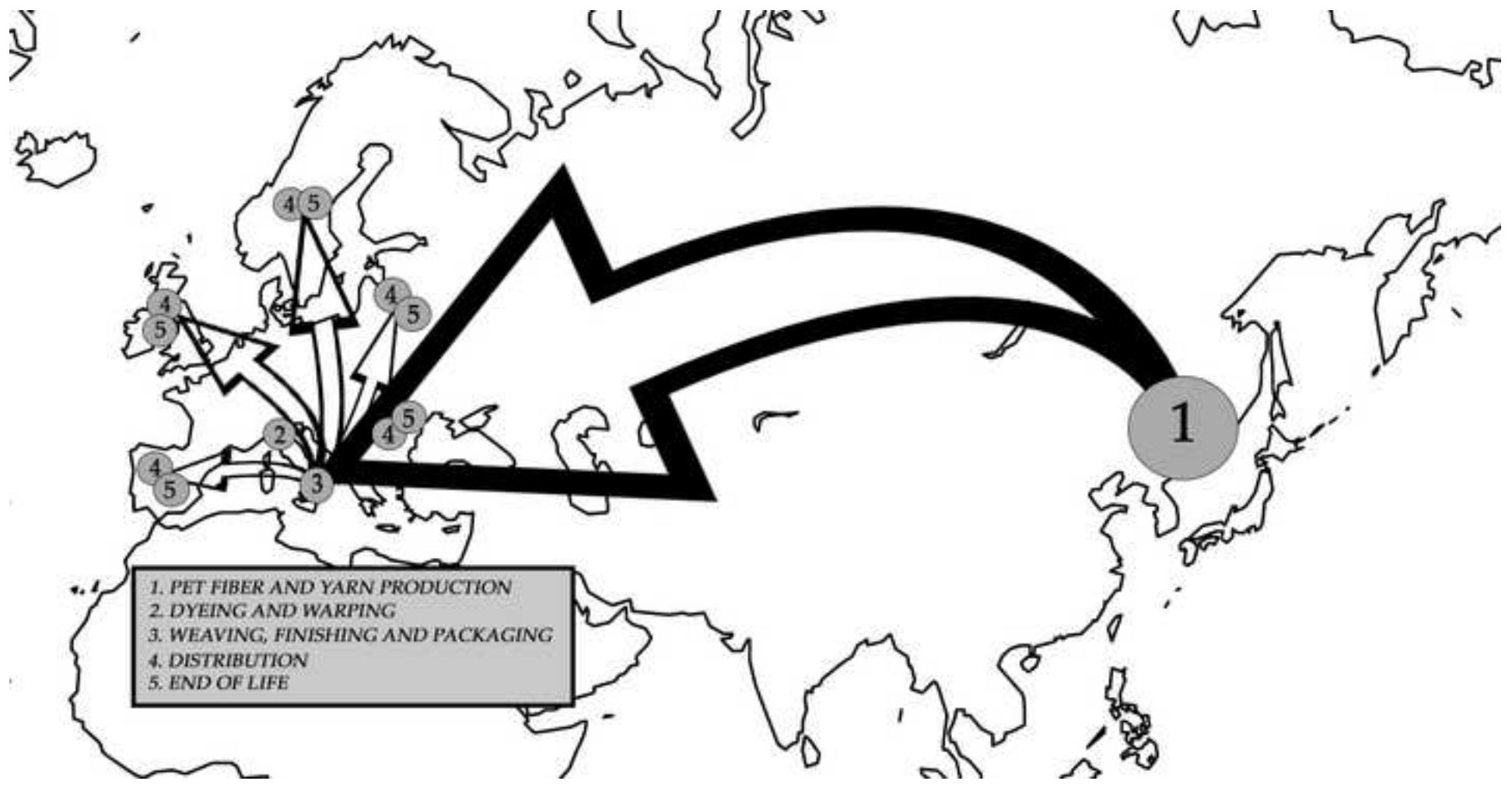
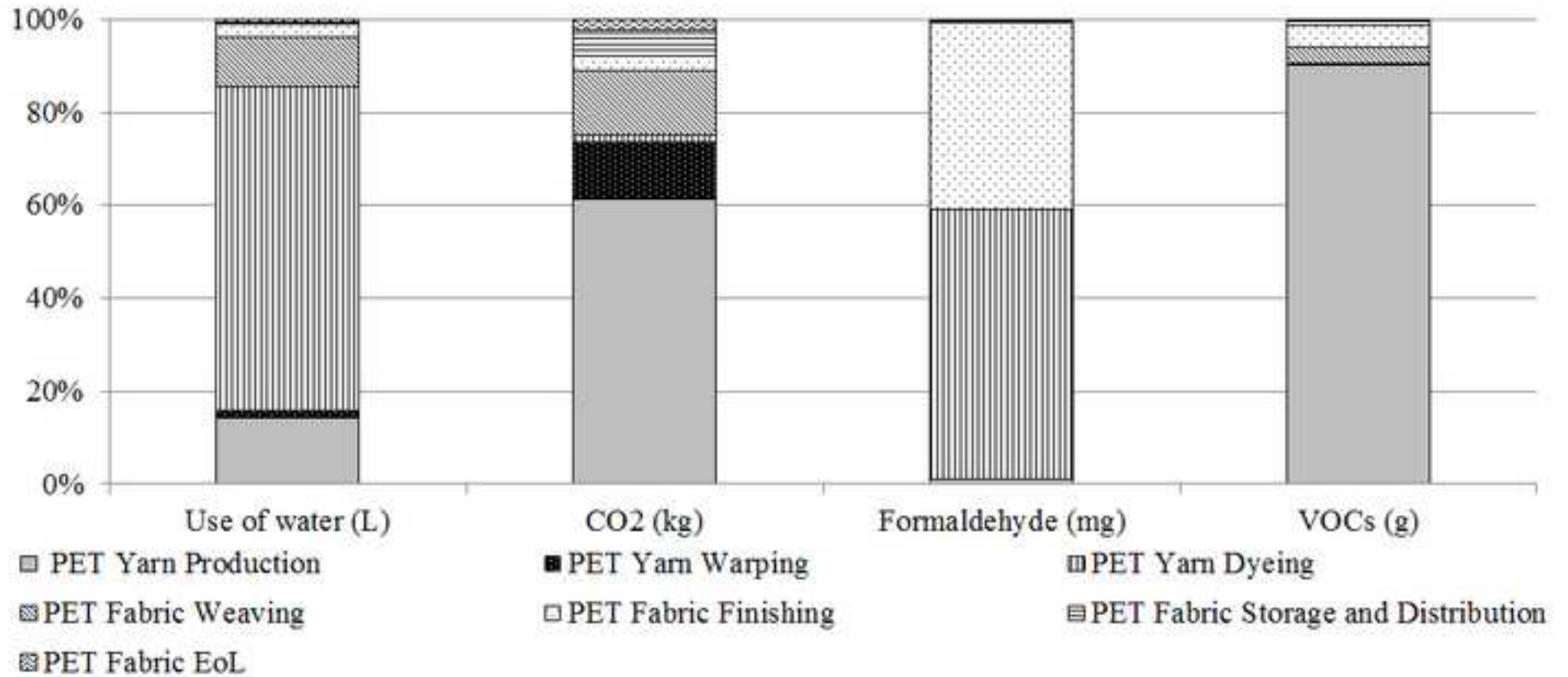


Fig. 4 Monte Carlo Analysis.

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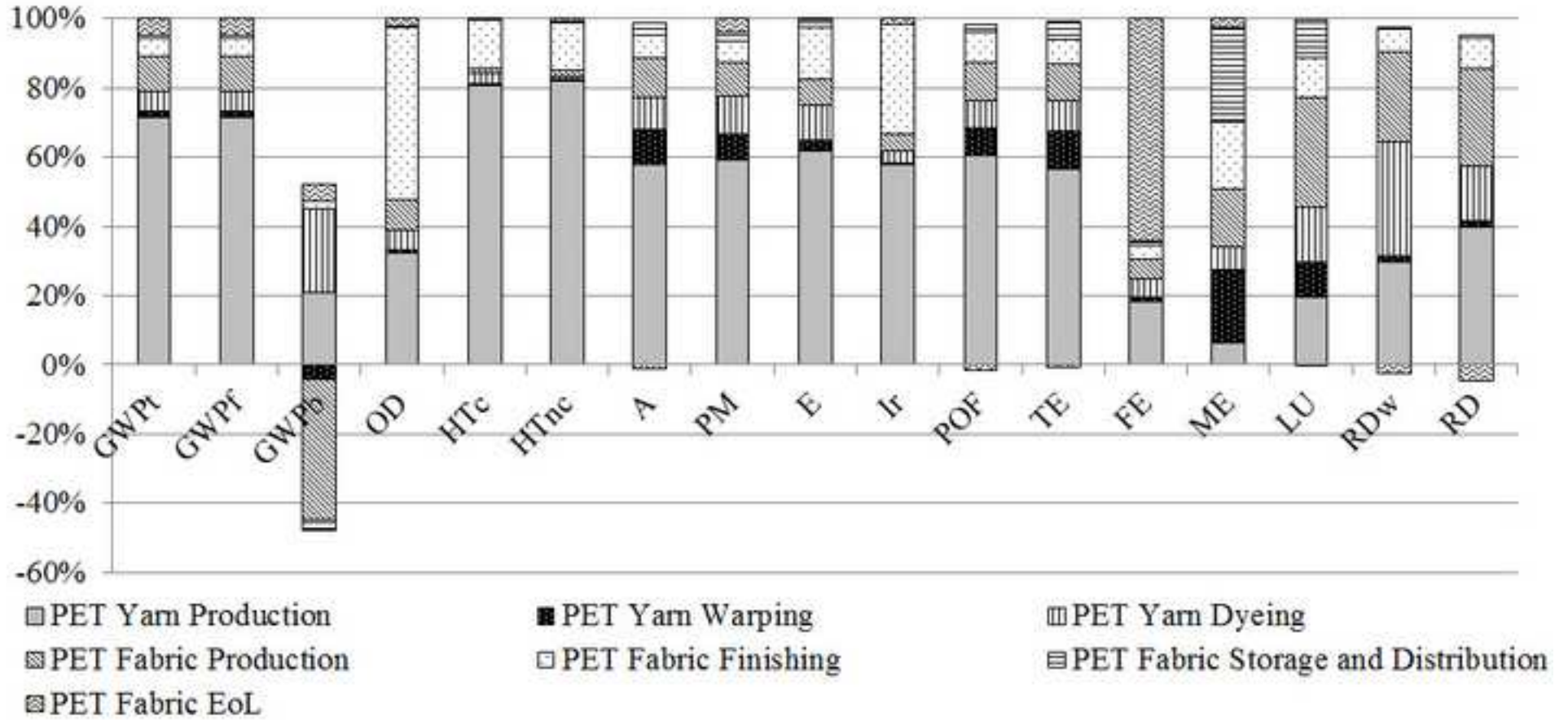
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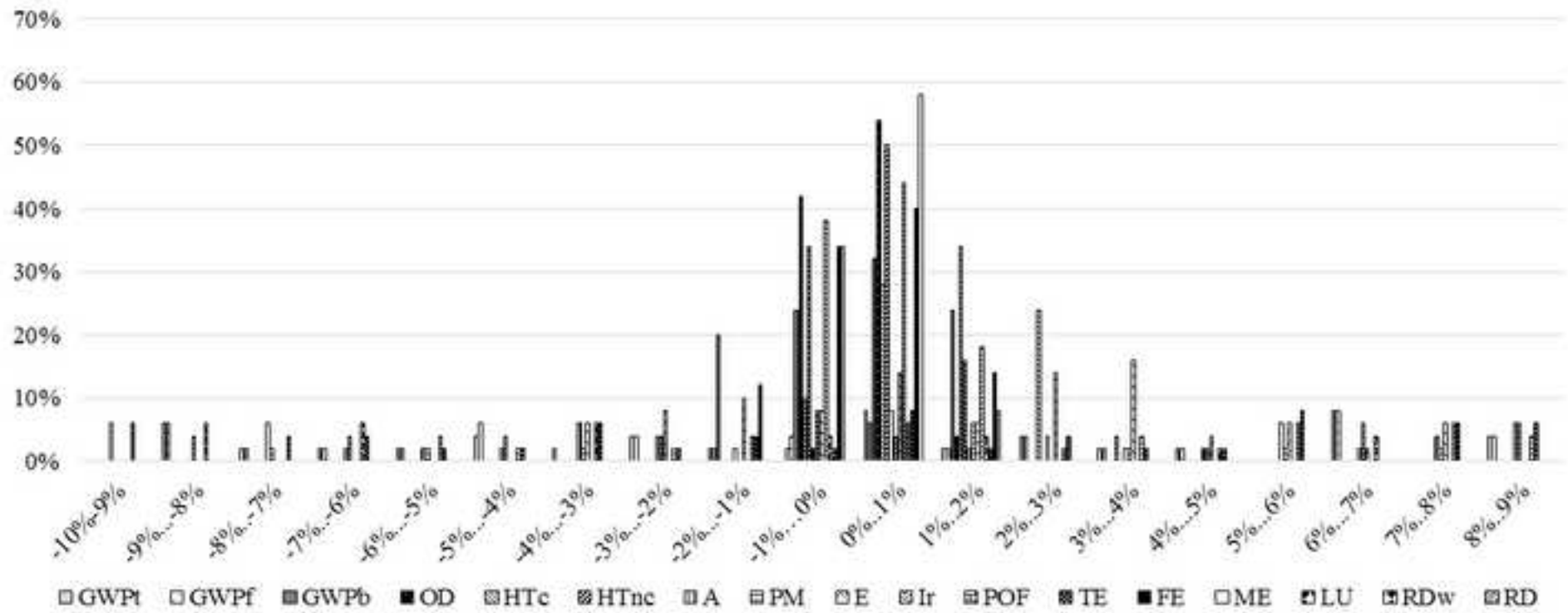
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fig_4.jpg

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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 concerning this manuscript to pasqua.labbate@poliba.it

Looking forward to hearing from you,

Yours sincerely

Dr Pasqua L’Abbate

Department of Civil, Environmental, Building Engineering and Chemistry,
Polytechnic of Bari,
4, Orabona Street,
Bari,70125,
Italy

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

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

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	<i>Base scenario:</i>		<i>Scenario A:</i>		<i>Scenario B:</i>		<i>Scenario C:</i>		<i>Scenario D:</i>		<i>Scenario E</i>	
	<i>PET from China</i>	<i>Yarn EOL 50% incineration 50% landfill</i>	<i>PET from Turkey</i>	<i>Yarn EOL 50% incineration 50% landfill</i>	<i>PET from Slovakia</i>	<i>Yarn EOL 50% incineration 50% landfill</i>	<i>PET from Italy</i>	<i>Yarn EOL 50% incineration 50% landfill</i>	<i>PET from China</i>	<i>Yarn EOL 100% incineration</i>	<i>PET from China</i>	<i>Yarn EOL 100% landfill</i>
GWPt	1.50E+01		1.12E+01		<u>8.95E+00</u>		1.12E+01		1.56E+01		1.43E+01	
GWPf	1.50E+01		1.13E+01		<u>8.95E+00</u>		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		<u>-3.61E-04</u>	
OD	1.23E-10		1.54E-10		1.61E-10		1.53E-10		<u>1.22E-10</u>		1.23E-10	
HTc	2.38E-08		2.40E-08		2.38E-08		2.40E-08		<u>2.36E-08</u>		2.39E-08	
HTnc	2.74E-06		2.77E-06		2.78E-06		2.76E-06		<u>2.71E-06</u>		2.76E-06	
A	3.55E-02		2.71E-02		3.84E-02		<u>2.66E-02</u>		3.47E-02		3.63E-02	
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LU	4.86E-01		8.94E-01		8.28E-01		8.67E-01		<u>4.64E-01</u>		5.08E-01	
RDw	3.96E-02		6.86E-02		1.35E-01		6.86E-02		<u>3.83E-02</u>		4.09E-02	
RD	4.55E-06		8.30E-06		6.98E-06		8.29E-06		<u>4.28E-06</u>		4.83E-06	

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

<i>Phase</i>	<i>Input/Output</i>	<i>Standard deviation</i>		<i>Reference</i>
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