LCA: a decision-making tool for recycling processes in textile industry

Sandrine Pesnel[1,*] and Anne Perwuelz[1,2]

[1] Ecole Nationale Supérieure des Arts et Industries Textiles (ENSAIT), Laboratoire de Génie et Matériaux Textiles (GEMTEX), 59056 Roubaix Cedex 01, France

[2] Université Lille Nord de France, F-59000 Lille, France

*Sandrine.Pesnel@ensait.fr

Abstract In the textile industry, different recycling processes are available to treat wastes. To help manufacturers to choose the most relevant solutions for their products, the Life Cycle Assessment tool can be used. First, we study the recycling of short fibres for cotton bed sheets. The study shows that the recycling of short fibres in a carded process significantly reduces some impacts such as the water consumption and eutrophication potential. Then, three recycling processes are compared for the treatment of post-consumer polyester trousers: the chemical recycling, the mechanical recycling and the energy recovery approach. In this case, the Life Cycle Assessment is used both to compare the processes and to study the influence of the following parameters: consideration of waste collection, the choice of substituted virgin products and the location of the recycling step.

1 Introduction

Nowadays, companies take more and more into account the environmental aspects because of legislation or ecological concern. In the textile industry, this environmental approach can be realized from the design of the product. For example, it is possible to produce an item made of organic cotton or to use a more eco-friendly dyeing process.

The introduction of recycling processes is also a way of eco-design. These processes can be realized at different levels of the life cycle: during the production or at the end of life of the textile product (recycling of post consumer waste). There are three kinds of recovering: the use as secondary raw material (the recycled material is re-used in the initial cycle), the use for another application in the textile sector, and the use in a new line of business. Manufacturers must choose the most relevant solutions, among many possibilities, for their products. To make their decision, they can use the Life Cycle Assessment (LCA).

In this study, we focused on the environmental assessment of recycling processes of two textile products: cotton (CO) bed sheets and polyester (PET) trousers. We quantified, according to the LCA methodology, the impact of the following recycling processes:

- for the cotton bed sheet : the re-use of short fibres resulting from the combing process in a carded spinning during the production stage,
- for the polyester item at the end of life : the chemical or the mechanical recycling.

Thus, the recycling processes are different because of their nature (chemical or mechanical processes) and the considered textiles (nature: cotton or polyester, and form: fibres or fabrics). For polyester item, these recycling processes are compared to energy recovery approach and landfill.

First, these studies quantify the specific environmental advantages of each recycling process. We can compare several processes and determine the most relevant one. Then, the hypotheses are modified to take into account other parameters, such as the location of the recycling step, the avoided production and the waste collection, and study their influence on the impacts.

2 Materials and methods

2.1 Generalities

The Life Cycle Assessment is realized thanks to the software GaBi 4 (software and database for Life Cycle Engineering, PE INTERNATIONAL AG, Stuttgart). The items, bed sheets and polyester trousers, are studied with the method system expansion to avoid allocation. The CML 2001 (updated in November 09) is used to calculate the environmental impacts.

The data come from the GaBi software and ELCD databases in general. For more specific processes like chemical recycling of polyester, data come from a patent and publications [1,2].

The different systems are presented in the following sections.

2.2 Re-use of short fibres resulting from the combing process in a carded spinning

In the case of carded spinning, all fibres (long fibres and short fibres) are used to produce the yarn. To increase the quality of the yarn, it is possible to add a step in the production phase: fibers combing. The combing process removes short fibers and thus only the long fibers are used. In industry, short fibers are recovered and used in a carding process.

Two bed sheets were studied in order to analyze the re-use of short fibres after a combing process: a percale bed sheet from a combed spinning process and a conventional bed sheet from a carded spinning process. The functional unit chosen for this study is "wash and use a carded bed sheet and a combed bed sheet for a year" (size of sheets: 240 x 300 cm). Figure 1 shows the system boundaries. The use phase consists in a washing every two weeks and an ironing of 10 minutes (cotton setting). The study also includes the sewage treatment of waste water from the finishing processes. The following elements are outside the system boundaries: infrastructure, maintenance of machinery (washing the dyeing equipment for example), transportation, packaging and distribution.

Several elements are taken into account in this study:

- Small increase in the lifetime of the combed bed sheet (72 washings instead of 60)
- Increase of energy consumption due to the additional step
- Increase of waste quantities for combed spinning process
- Waste management: recycling the short fibres or not

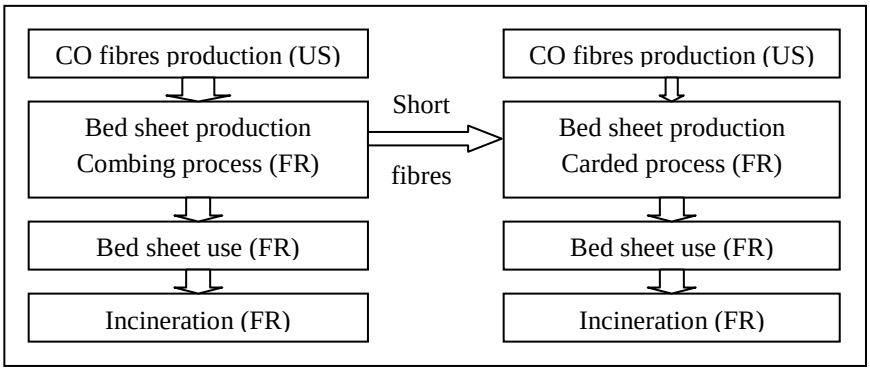

Fig.1: System boundaries (location of each step: FR: France, US: United States)

2.3 Recycling of a polyester item at the end of life

2.3.1 Study of the processes

The environmental impacts of polyester recycling processes are studied. The system boundaries are the treatment of the polyester trousers and the manufacture of recycled products. The functional unit is "the treatment of 1 kg of French post-consumer polyester trousers". The recycled products can be seen as substitutes for virgin products. Therefore, a credit for the avoided production of equivalent virgin products is given to each recycling scenario. To study only the influence of recycling processes, the avoided production is located in the same place than the recycling process (in Japan for chemical recycling, and in France for mechanical recycling and energy recovery approach). Thus there is no influence of energy and thermal mixes.

Three recycling processes are compared: the chemical recycling, the mechanical recycling and the energy recovery approach (which leads to the production of energy and steam) (Fig. 2). The landfill is taken as reference in the study.

The chemical recycling is composed of two main steps: a depolymerization to obtain the starting monomers (by methanolysis), and a polymerization. This recycling allows to obtain a 100 % recycled polyester yarn which is used to produce new trousers (closed-loop recycling).

The mechanical recycling involves shredding post-consumer trousers to obtain fibres. These fibres are used to produce a nonwoven thermal insulation for building sector (open-loop recycling). This textile nonwoven avoids the manufacture of a glass wool insulation (conventional thermal insulation). However, polyester and glass wool insulations do not have the same properties (different thermal conductivity and density) so 1 kg of polyester insulation is not equivalent to 1 kg of glass wool. The reference unit "insulate a wall of a house for 50 years to respect the RT2012 regulation (thermal performance R = 5 m^2.K/W)" and the properties of each material are used to calculate the avoided quantity of glass wool. The recycling of 1 kg of post-consumer polyester trousers substitutes the manufacture of 0,74 kg of glass wool.

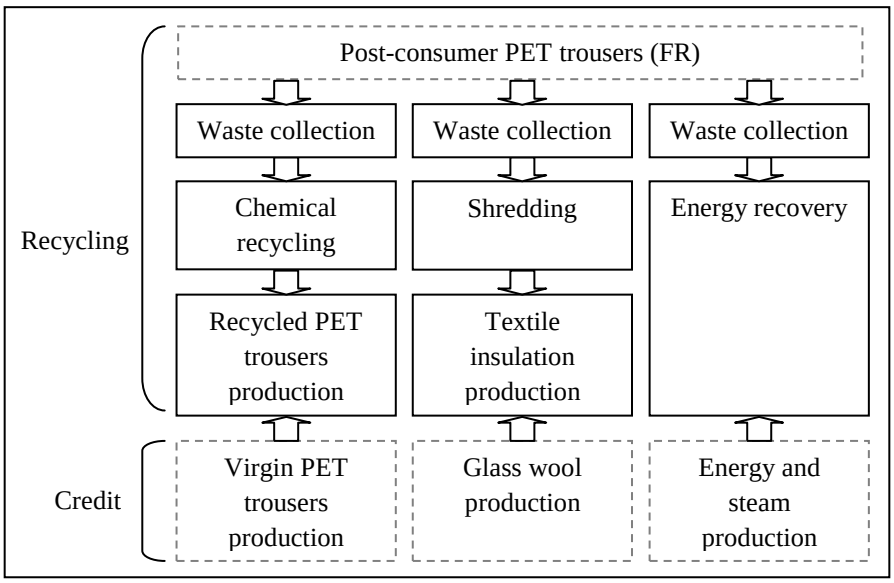

Fig.2: Treatment of post-consumer polyester trousers (system expansion)

2.3.2 Sensitivity analysis

For the chemical recycling, the sensitivity analysis focuses on the location of the recycling step: in Europe instead of Japan.
The location of the avoided product is also studied (virgin polyester yarn and virgin polyester trousers productions). Actually, the polyester resin is mainly produced in China. So, manufacture of recycled items in Japan can substitute virgin polyester trousers produced in China and imported to Japan. In this case, the credit corresponds to trousers which are produced in China instead of Japan. Only the influence of energy and thermal mixes are taken into account to study the different scenarios.

For the mechanical recycling, the influence of the recycling step location is analyzed. Different countries are studied, Belgium, Germany, United Kingdom and Italy, instead of France. Only the influence of energy mix is taken into account to study the different scenarios.

To study the influence of transport, the waste collection is added to the system boundaries.

3 Results

3.1 Re-use of short fibres resulting from the combing process in a carded spinning

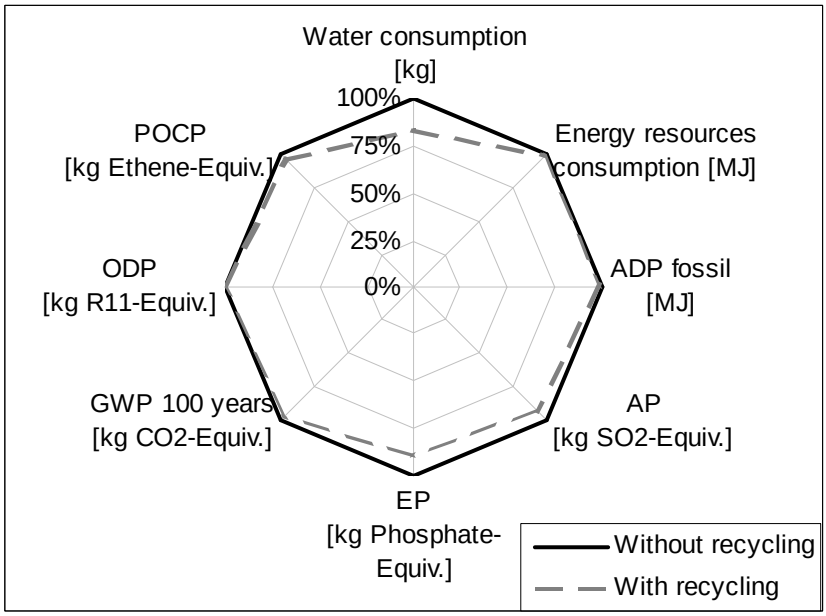

Fig.3: Environmental impacts of bed sheets with and without recycling (ADP: Abiotic depletion potential, AP: Acidification Potential, EP: Eutrophication Potential, GWP: Global Warming Potential, ODP: Ozone Depletion Potential, POCP: Photochem. Ozone Creation Potential)

When the recycling of the short fibres is taken into account in the study, the environmental impacts for the life cycle of the two bed sheets decrease. The water consumption decreased by about 15 % and eutrophication potential about 10 % (Fig. 3).

3.2 Recycling of a polyester item at the end of life

3.2.1 Study of the processes

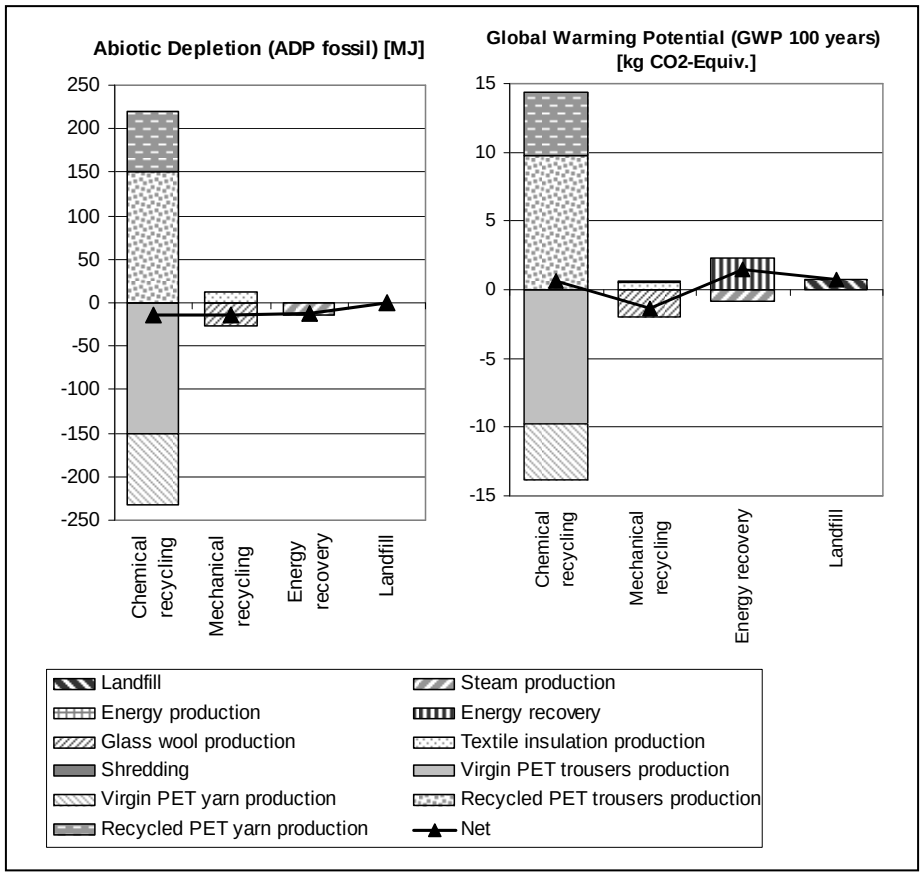

Fig.4: Results for the study of the recycling processes: Abiotic Depletion Potential and Global Warming Potential

We can see that whatever the recycling process is, the net value is near to zero.

The net results for abiotic depletion impact show that all recycling processes give approximately the same results reducing the consumption of fossil resources (Fig. 4).

However for the global warming potential, the mechanical recycling differs and is the most favourable recycling process. The high impact obtained for the chemical recycling is due to the high energy consumption. The results are consistent with the study of Jun Nakatani *et al*. [3].

For the energy recovery approach, the impacts are due to the air emissions which take place during the incineration.

3.2.2 Sensitivity analysis

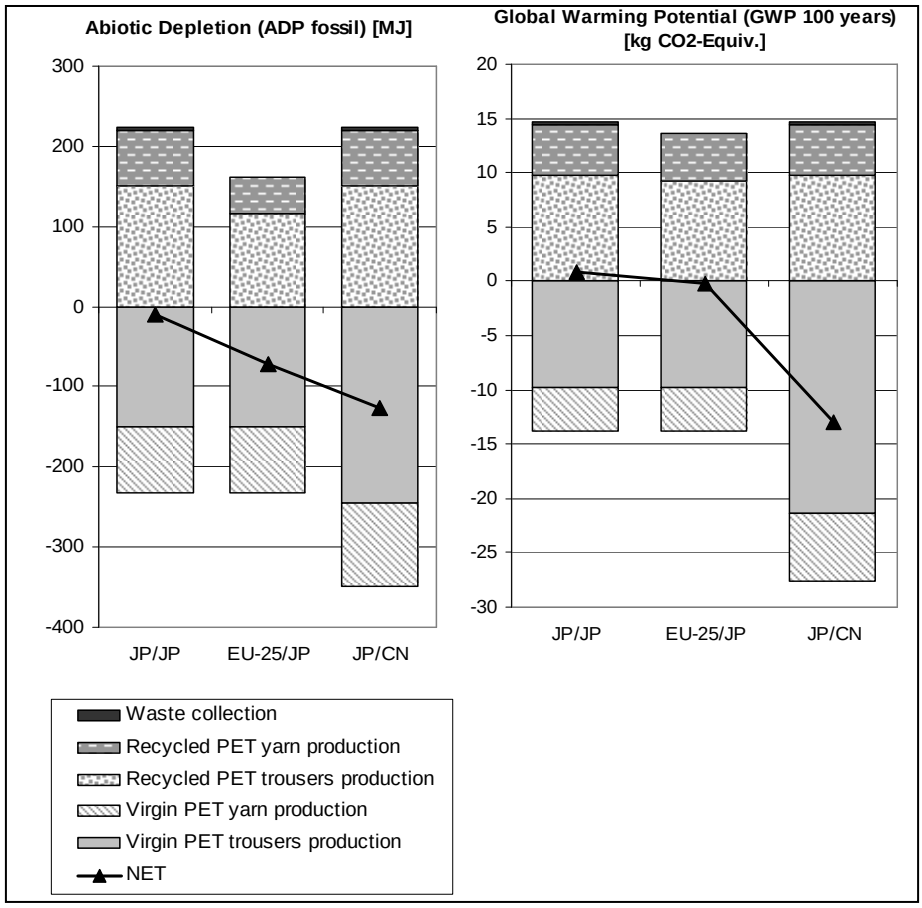

Fig.5: Results for the sensitivity analysis for the chemical recycling: Abiotic Depletion Potential and Global Warming Potential. Legend: JP/JP location of the recycling step / location of the virgin product (JP: Japan, CN: China, EU-25: Europe)

Recycle in Europe instead of Japan leads to a decrease of the impact due to the waste collection. However, in general, transport phase has a small impact (Fig. 5).

These results show significant differences between the studied scenarios. The chemical recycling is less impacting if realised in Europe than in Japan. The results also show that the production of the virgin polyester trousers is more impacting in China than in Japan.

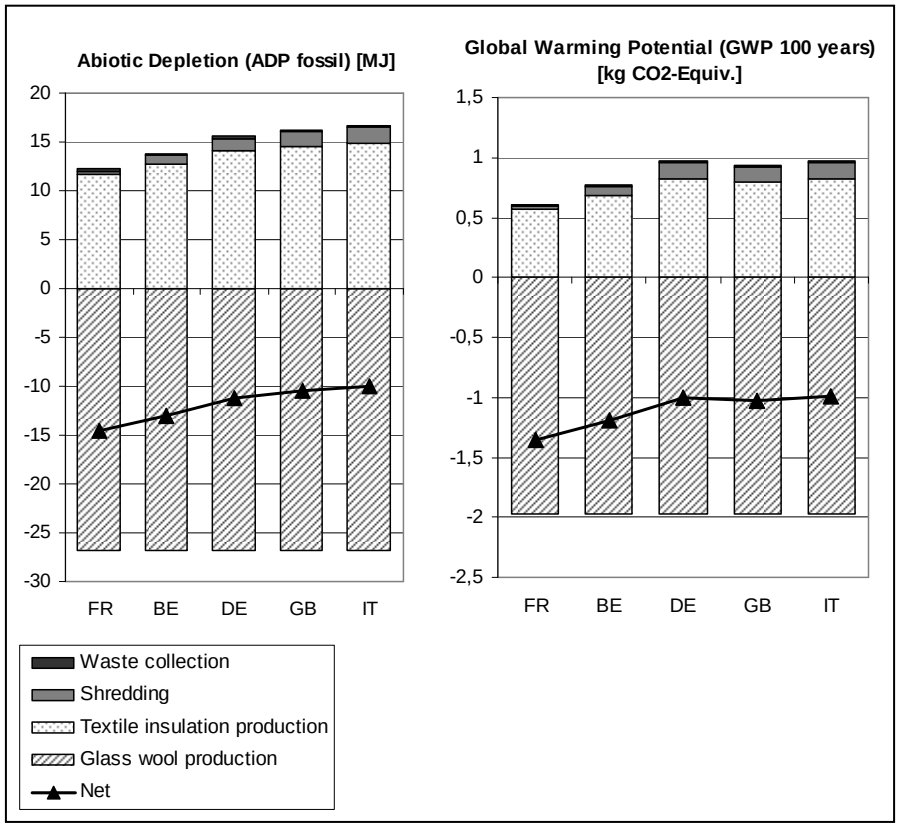

Fig.6: Results for the sensitivity analysis for the mechanical recycling: Abiotic Depletion Potential and Global Warming Potential. Legend: FR location of recycling step (FR: France, BE: Belgium, DE: Germany, GB, United Kingdom, IT: Italy)

As for chemical recycling, the waste collection has a small impact compared to the production of polyester insulation (Fig. 6).

The smallest impact is obtained when the recycling takes place in France. Conversely, the most significant impacts are found for Italy (and Germany for global warming potential). However, this study is only about two impacts. It is necessary to study a larger number of indicators (for exemple, the impact due to nuclear power) to have a global view.

4 Discussions

4.1 Influence of the recycling phase

The study on cotton bed sheets shows that the recycling of short fibers leads to a significant decrease of results for water consumption and eutrophication potential. These two indicators are directly related to cotton cultivation. Indeed, the cultivation of cotton requires a large amount of water, almost 1300 L for 1 kg of fibers [4] and many chemicals (fertilizers, pesticides...) [5]. These products are partly removed in water and contributing to its eutrophication. The recycling of short fibres reduces the amount of cotton produced for the carded sheet which leads to a decrease of these indicators.

4.2 Study of processes, influence of parameters

The study of processes indicates that mechanical recycling is the most attractive alternative compared to chemical recycling and energy recovery approach for the global warming indicator.

The study of processes allows us to obtain specific information processes disregarding external parameters such as the stage of waste collection, the location of the recycling step and location of the production of virgin material. However, when LCA is used as a tool for decision making to select the best solution of a supply-chain, these parameters must be taken into account.

The results show that the location of the recycling step affects environmental impacts of recycling via the energy mixes used in each country. The differences are particularly important in the case of chemical recycling for abiotic depletion indicator. This parameter is directly related to the geographical location of the factory, and can be easily configured.

The location of the production of virgin material is proving to be an important parameter. In fact according to the location of the production of the virgin polyester, China or Japan, significant differences are obtained for the chemical recycling.
The more the impact due to the production of virgin material is important, the more interesting it is to recycle. When recycling processes are studied, this parameter should be studied in a sensitivity analysis because a recycled product does not consistently substitute a virgin product in the same country, the substitution can focus on an imported product.

Concerning the waste collection of polyester trousers recycling, the results show that this step has not a significant impact compared to others, whether for chemical or mechanical recyclings.

5 Conclusions

The study on bed sheets indicates that it is important to take into account the recycling phase in the study of a product.

As a decision making tool, LCA allows to realize full studies by taking into account the following parameters: the location of the recycling step and the characteristics of the avoided product (including place of production). These parameters result in significant variations of impacts (particularly for the chemical recycling) which can be sources of error if they are not taken into account.

LCA can be used to study the recycling processes, but also to determine in which country a manufacturer should implement the recycling plant. LCA can also be used as an optimization tool of processes showing hot spots to improve.

6 Acknowledgments

This work was realized within the framework of ACVTEX project which is financed by Europe (Interreg and FEDER), Conseil Régional du Nord – Pas-de-Calais, ADEME, DIRECCTE and Région Wallone. The authors gratefully acknowledge the help provided by Vanessa Pasquet.

7 References

[1] Teijin Limited, Method for recycling PET bottle, US Patent n°7,462,649, 2008

[2] M. Genta, F. Yano, Y. Kondo, W. Matsubara, S. Oomoto, Development of chemical recycling process for post-consumer PET bottles by methanolysis in supercritical methanol, Mitsubishi Heavy Industries, Ltd., Technical review, Vol.40 Extra No.1, 2003

[3] J. Nakatani, M. Fujii, Y. Moriguchi, M. Hirao, Life-cycle assessment of domestic and transboundary recycling of post-consumer PET bottles, *International Journal of Life Cycle Assessment*, Vol. 15, No. 6, 2010, 590-597.

[4] National Renewable Energy Laboratory, U.S. Life Cycle Inventory (LCI) Database, 2000

[5] Danish Environmental Protection Agency, EDIPTEX - Environmental assessment of textiles, Version 1.0, 2007