

WP T2 - INNOVATION ON TEXTILE WASTE MANAGEMENT

ACTIVITY A.T2.3 PILOT CASES

D.T2.3.2 PILOT CASES

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ENTeR - Expert Network on Textile Recycling

ENTeR works in five central European countries that are involved in the textile business, to promote innovative solutions for waste management that will result in a circular economy approach to making textiles.

The project will help to accelerate collaboration among the involved textile territories, promoting a joint offer of innovative services by the main local research centres and business associations (“virtual centre”), involving also public stakeholders in defining a strategic agenda and related action plan, in order to link and drive the circular economy consideration and strategic actions.

The approach of the proposal and the cooperation between the partners is oriented to the management and optimization of waste, in a Life Cycle Design (or Ecodesign) perspective.



1. Pilot case description - aim and scope

Alfredo Grassi S.p.A.

The company owns six production units located both in Italy and abroad, where work more than 1000 employees: Lonate Pozzolo, historical headquarters and Research and Development centre (90 employees); Targu Trotus, Comanesti, Bogdanesti and Giorgiu in Romania (650 employees), Librazhd in Albania (100 employees), and Korba in Tunisia (280 employees).

The group has a production capacity of 1.500.000 linear meters of fabric per year and a production of more than 3.500.000 garments per year.

Production is organized along a vertical process whereby there is a complete control of all the production phases, from weaving through cutting to manufacturing the finished product. Thanks to the synergy among the different production sites is possible to manage and supervise the whole process, from design to delivery, according with UNI EN ISO 9001:2000.

Alfredo Grassi S.p.A. garments are manufactured using excellent quality raw materials and advanced components. High-tech production machines, among which last generation computerized looms, automatic cutting machines, laser cut instruments, press machines for special applications, seamless technology and feather filling machines, allow the manufacturing of high-tech garments.

Moreover GORE-TEX GOLD level license integrates the quality and technology standard of the process in the subsidiary of Targu Trotus, for the production of waterproof and breathable garments.

Key-word of our work has always been maximum flexibility. This allow them to focus on the personalization of each garment according to specific technical, design and production features the customer requires, providing every time tailor-made solutions and quotations.

The raw material used aims to a sustainable production process and guarantees high durability to the garment.

For years Alfredo Grassi S.p.A. has been collaborating with suppliers who support environmental policies in total agreement with its ideas and commitments in the field of sustainability.

In recent years Lonate Pozzolo headquarters have adopted the photovoltaic system and installed 5.000 m² of solar panels for a total electricity production of 400.000 KW per year.

Alfredo Grassi S.p.A. holds SA8000 certification, that assesses corporate practice on a wide range of issues and evaluate the state of a company's management systems, necessary to ensure ongoing acceptable practices.

The main elements are respect of human rights and labour rights, protection against child labour or discrimination, health and safety care.

The standard is applied to all activities, products and services made by the company and involve all company's roles, from top management to employees and suppliers.



1.1.1. Characterisation and current handling of the waste stream

Alfredo Grassi S.p.A. offers a great range of products developed to meet the needs of different markets, such as:

- Protective garments for Fire Fighters, petrolchimic industry, arc flash equipment etc.;
- Waterproof garments: in Gore-Tex or equivalent material;
- Public uniforms: technical and protective garments for the Army, Law Enforcement Forces, Fire Fighters etc.;
- PPE: in accordance to European norms;
- Company personalized product lines for different fields;
- High Visibility garments;
- Workwear.

The addressed company produces a huge amount of garments for the listed sector, roughly more than 3.500.000 per year.

These garments can vary from first layer indument (shirts, polo shirts, t-shirts, pants) and intermediate layer (sweater, fleece, sweatshirt, pullovers, trousers) to outer layers (coveralls, jackets, parkas, gilet, waterproof suits, ...) and accessorise (caps, shoes, gloves).

Their composition could be very different: Cotton, Wool, Silk, Lyocell, Modal, Viscose, Polyamide, Polyester, Polyacrylic, Polypropylene, Polyurethane, Aramid or a mix of them. And also fabric characteristics could vary (weight, weaving, yarn type, etc).

Some of the garments have also a finishing applied on them, such as water repellent, flame retardant, UV protection, etc).

Furthermore the textile component could be linked to non textile accessorise, such as buttons, zippers, chips and fasteners, but also composite materials (high visibility strips, ballistic protection blocks, etc).

All these products are fully catalogued, with information about their composition, textile, finishings, accessories, design, quantity, date of production etc. Thanks to this detailed digitalised catalogue, the company can monitor the characteristics of each waste and find all the information required for their management.

The problem of waste management addressed by the company deals with the management of old (and expired) garments stocked in their storehouse, and with the used garment recollected from their customers after use.

In the first case waste consists of garments (older than 5 years) produced and never sold, or stocked in their storehouse for their customers (company offered service) and never used (biggest and smallest sizes). They have never been used or washed, and correspond exactly to the produced item. Unfortunately they cannot be sold because they PPE certification could be expired or because they have private logos on them (sewed, printed or transferred) and couldn't easily be removed.



In the latter case garments are used by operators, sometimes for long periods, and have lost their characteristics and could not correspond exactly to the original sold garment (lost of accessories, damages on textile, decrease of finishing properties due to laundry, etc).

Up to now the stock post industrial waste is stocked in their storehouse and become a big problem to deal with, since it is periodically picked up (for free) from stockists. They are trying to sell the garments, accessories and textiles that can easily be re-placed on the market.

The garments coming from post consumer use are now recollected to offer a useful service to their customer, but usually are disposed as urban waste (landfill or incineration).

1.1.2. Importance / position of the concerned type of textile production within regional textile sector

In Lombardy, the Textile and Clothing Sector is composed of 13,570 active enterprises (source: Movimprese, 2017) and employs more than 95,000 people (source: ISTAT, 2015). The regional textile sector accounts for 17.4% of the total number of local units of the sector in Italy (source: ISTAT, 2015). The local units are placed in the province of Milan (they account for 4.9% of Italian local units of the sector), Varese (2.5%), Brescia (2.1%), Bergamo (1.8%) and Como (1.7%). The Textile and Clothing Sector includes two sub-sectors:

- manufacture of textiles (production and finishing, like laminating, coating and dyeing) with 3,955 active enterprises (source: Movimprese, 2017);
- manufacture of wearing apparel, with 7,770 active enterprises (source: Movimprese, 2017).

Considering the above mentioned overview of the sector Alfredo Grassi's production falls within all these sub-sectors. Their textile waste is diversified according to material composition, texture, fibers, finishing.

As regards waste volumes produced in Lombardy, we analysed data of MUD 2017 (Environmental Declaration Model) related to waste produced in the textile sector in 2016. These are the resulting data: 118,465 tons/year of which 102,996 tons/year (86.9%) comes from textile industries, while the remaining 15,469 tons/year (about 13.1%) comes from production processes of clothing and articles in leather and fur.

45,129 tons/year, equal to 38.1% of the total amount, are characterized by waste deriving from leather and fur processing and textile industrial waste: the former is mainly composed of tanning liquids containing chromium (not dangerous), sludges coming from on-site treatment of effluents and waste, scrap and polishing powders, all leather processing waste. The latter is composed by solid waste from composite materials production (impregnated fibers, elastomers, waste from finishing containing solvents and non-solvents) as well as dyes, pigments, sludges from on-site effluent treatment. Such waste, depending on the production activity from which they derive, may contain dangerous substances which complicate the recovery and recycling actions.

1.1.3. Other relevant information

Grassi 10000 [GR10K] is a project and collaboration-based platform.

Born out of Alfredo Grassi S.p.A., a family business manufacturer of workwear since 1925, it promotes ideas on labour and uniforms. Its primary purpose is to promote and sustain the values

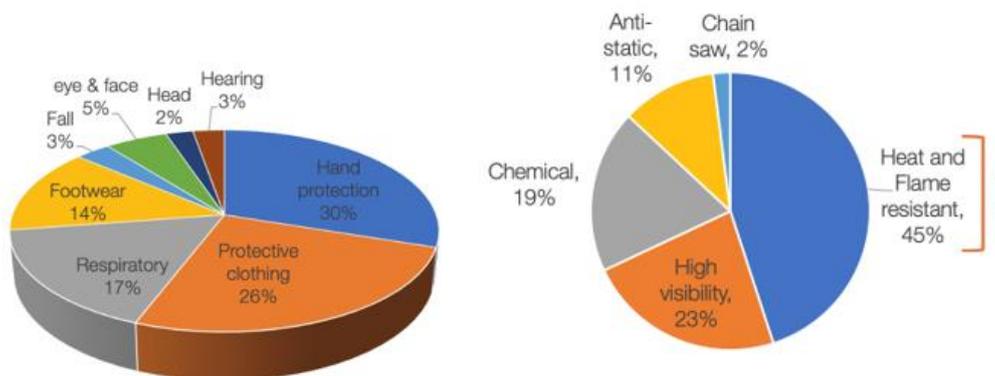


intrinsic to the company itself, developing and spreading the aesthetics of uniforms, commercial initiatives and research projects, called assemblies. The secondary intention is to investigate resourceful textile production processes, via current fashion infrastructures.

ASSEMBLY 1 [A1] is a collection of clothes reinterpreting blue collar staples from the archive of Alfredo Grassi S.p.A.. A1 is produced in an ongoing blue edition and in limited editions, produced with dead-stock fabrics of Grassi and his suppliers. Repurposing material left over from workwear production, GR10K tries to investigate resourceful textile production processes. The collection is accompanied by a text by architect and writer Jack Self, commenting on THE VALUE OF THE UNIFORM.

2. Definition and analysis of a circular supply chain for fr protective garments

1. The European PPE market



Total PPE 10.8 billion \$ in 2019

Europe is the second largest PPE (Personal Protective Equipment) market in the world after North America. The PPE market in Europe is about 10.8 billion \$ in revenue. Protective clothing is the second largest PPE category representing a quarter of the PPE market.

FR protective clothing market represents about 45% of the total protective clothing market.

2. FR Protective clothing: fibre in use

In thermal protective clothing, there is a need for high-performance fire-retardant/resistant textile fibers. There are two main categories of fire-retardant and fire-resistant fibers:



3. Fire-retardant fibers

Fire-retardant fibers are of chemically modified fibers. Flame retardant fibers are not flame-resistant or flame-proof but they are designed to slow down the spread of fire. They might also be self-extinguishing. When exposed to heat or flame, the chemical application will expel gases to help to suppress and slow the spread of the fire.

Fire-retardant fibers are FR Polyester, FR Nylon, Modacrylic, Viscose FR.

4. Fire-resistant fibers

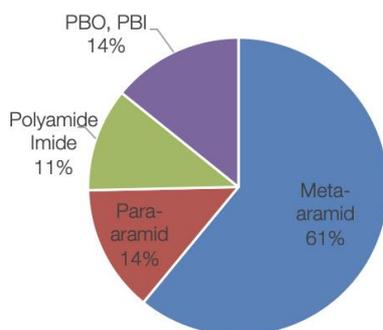
Fabrics made with fire-resistant fibers are inherently flame resistant. These fabrics will not melt, drip or support combustion in the air.

When exposed to extreme heat, flame resistant fibers changes its properties This reaction increases the protective barrier between the heat source and the skin when workers need it most.

Main flame resistant fibers are: Meta-Aramid (Nomex®, Teijinconex®, Heracron®), Para-Aramid (Kevlar®, Twaron®), Polyamide Imide (Kermel®), Polybenzimidazole (PBI), Polybenzobisoxazole (PBO).

The preference today is to use fibre blends that take advantage of the beneficial properties of several fibre types.

Meta and para-aramid are the main inherently fire-resistant fibres used in protective clothing.



Use of fire-resistant fibers in FR protective clothing

5. PPE and sustainability

Due to the pandemic, the use and disposal of single use Personal Protective Equipment (PPE) has reached unprecedented levels. All the debate about sustainable PPE is nowadays around the protective equipments related to healthcare, which is fully comprehensible and most probably beneficial for a more long-term sensitivity for the subject in other, broader areas of professional workwear.



This situation should have a positive impact on how Governments and Public Administrations will review their specs for PPE supplies, not only for medical and healthcare protection, but in all sectors. The New Green Deal Program in the EU will also be a strong driver for such a move.

Already in pre-COVID19 era, some encouraging signs of increased attention towards a sustainable supply chain in PPE have been introduced in the setup of calls for garments and uniforms, with a “bonus” for proposals that could guarantee a reliable and traceable use of recycled materials in the process.

For what concerns FR protective clothing, the technical performance and consequent compliance to severe standards and norms are apparently a constraint and risk to be an obstacle for the use of recycled textiles.

With the present study we focus the attention on how both technical performance and sustainability can match, if we look into garment construction with accuracy.

3. Textile Wastes : Laws And Norms

1. Currents norms in Italy and EU

Despite the textile and apparel business is global with involvement of many countries worldwide, the regulations around the management of textile wastes remain at local level. This situation does not help in having a global overview and a strategic vision for a harmonized approach to circular economy in this industry.

We will then focus our attention to the reference the legislation in Italy and at EU level.

Hereunder the milestones of the regulation system around waste and by-products, including textile and apparel.

1. DIRECTIVE 2008/98/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 April 2006 on waste
2. Regulation (EC) No 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste
3. COMMUNICATION FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT on the Interpretative Communication on waste and by-products, 21.02.2007
4. DIRECTIVE 2008/98/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 November 2008 on waste and repealing certain Directives
5. DECRETO LEGISLATIVO 3 aprile 2006, n. 152 Norme in materia ambientale.
6. MINISTERO DELL'AMBIENTE E DELLA TUTELA DEL TERRITORIO E DEL MARE, DECRETO 13 ottobre 2016 , n. 264 . Regolamento recante criteri indicativi per agevolare la dimostrazione della sussistenza dei requisiti per la qualifica dei residui di produzione come sottoprodotti e non come rifiuti.



7. MINISTERO DELL'AMBIENTE E DELLA TUTELA DEL TERRITORIO E DEL MARE, Circolare 30 maggio 2017, prot. n. 7619 - Circolare esplicativa per l'applicazione del decreto ministeriale 13 ottobre 2016, n. 264
8. Legge n. 128/2019, art. 14/bis (Cessazione della qualifica di rifiuto).
9. REGIONE TOSCANA - Delibera Giunta Regionale n.12 del 13-01-2020 - PRIME LINEE GUIDA PER L'APPLICAZIONE DEL REGIME DI SOTTOPIRODOTTO NELL'INDUSTRIA TESSILE

2. Threats and opportunities vs. a circular economy approach

The big effort made since 2006 in regulation at European and national level was essentially driven by the increased attention to environment and the necessity to fight against illicit and criminal trade and treatment of wastes.

In the following 15 years the growing sensitivity to circular economy has led the legislators to integrate more and more rules and consequent procedures about the recover-recycle-reuse process.

The result is a quite complex and knotty bureaucratic system that can sometimes discourage the textile/apparel players to fully play the game and consider circular economy a priority in their business strategy.

Two main topics are still worth to be better analyzed with the aim of defining simpler and clearer rules, where both respect of legal principles and good business practice can match in a win-win perspective:

- Difference between waste and by-products in all the steps of the supply chain. This is particularly important for the recovery of pre-consumer (or post-industrial) materials.
- Harmonization of import/export procedures as far as textile wastes or by-products are concerned, since it is well known that most of the garment manufacturing (and sometimes the fabric manufacturing) is located outside Italy and the UE.

Branded certification systems for traceability and consequent reliability of a recycled material, such as GRS - Textile Exchange are for sure welcome in this scenario.

Its worldwide diffusion is undoubtedly a boost for the industry and a very interesting strategic marketing axe to be developed and continuously updated and improved.

In particular a more streamlined certification management system could be more effective where the supply chain is fragmented among many small-medium enterprises (SME) with involvement of different textile materials, such as the Prato district, where the circular economy in textile was probably born two centuries ago.

4. A case study. setup of a “circular” supply chain for fr garments based on aramid fibers

1. Aramid fibers and their applications in flame resistant protective clothing

The characteristics of aramid fibers are particularly significant for all end uses where the protection from heat, flame and fire are concerned.

In particular:

- Military and Police
- Firefighters
- Industry
- Performance sportswear (eg. Motorsport racewear)

End use market – Military & Police

| | | |
|---|---|--|
|  <p>Advanced military combat clothing</p> <ul style="list-style-type: none"> • Fabric made with inherent FR fiber (aramid+ FR cellulosic) • Lightweight and resistant • Camouflage and infra red • Medium value |  <p>Military combat clothing</p> <ul style="list-style-type: none"> • Fabric made with inherent FR fiber (aramid+ FR cellulosic) • Lightweight and resistant • Camouflage • Medium to low value |  <p>Police special unit</p> <ul style="list-style-type: none"> • Fabric made with inherent FR fiber (aramid+ FR cellulosic) • Lightweight and resistant • Medium value |
|---|---|--|

Several generations of clothing co-existing

End use market – Firefighter

| | | |
|---|---|--|
|  <p>Turnout gear Outer shell</p> <ul style="list-style-type: none"> • Entirely Inherent HPF • Multilayers • High value • Woven and <u>non woven</u> |  <p>Wildlands</p> <ul style="list-style-type: none"> • Mostly Inherent HPF and traditional • One layer • Medium value • Woven |  <p>Station wear (underwear, head cover, fleece)</p> <ul style="list-style-type: none"> • Inherent traditional & HPF and treated • One layer • Medium to low value • Woven and knit |
|---|---|--|

Combination of multilayer FR underwear, station-wear and outer-shell is critical for overall protection

End use market - Industry

| | | |
|---|--|---|
|  <p>Oil & Gas, petrochemical</p> <ul style="list-style-type: none"> • Mostly Inherent HPF & traditional • 1 to 2 layers • High to medium value • Woven and non woven • Typically multi-risk: FR, ESD, Chemical |  <p>Utilities / manufacturing</p> <ul style="list-style-type: none"> • Inherent blends traditional and treated • One layer • Medium value • Woven |  <p>Welding</p> <ul style="list-style-type: none"> • Inherent blends HPF and traditional • One layer • Medium to high value • Woven |
|---|--|---|

Aramid fibers are man-made high-performance fibers, with molecules that are characterized by relatively rigid polymer chains. The term “aramid” is short for “aromatic polyamide”. Aromatic polyamides were first applied commercially as meta-aramid fibers in the early 1960s, with para-aramid fibers being developed in the 1960s and 1970s.

The main differences between meta- and para-aramid are linked to their production process (wet or dry spinning) and to the crystallinity level of their molecular structure.



As far as protective clothing against heat, flame and fire are concerned, meta-aramid fibre is the most suitable thanks to its high resistance to temperature (it does not burn or melt), chemical degradation and abrasion, as well as it is dyeable and has a relatively soft touch and feel.

The production of meta-aramid fiber is in the hand of a few man-made fibers producers in the world, such as DuPont (Nomex®), Teijin (Teijinconex®), Kolon (Heracron®), as well as some manufacturers in China. As a further step in the textile chain, the fibre is then transformed into yarn. In case of meta-aramid, staple yarn technology is dominant, while continuous filament production is negligible. Generally speaking the fibre producers are not vertically integrated with the spinning phase, so that they do not sell meta-aramid yarns on the marketplace.

The number of spinning companies who offer spun meta-aramid yarns is higher than the fibre producers, but it is still a limited group of specialized players.

In order to enhance its performance in protective clothing and the compliance to international standards of related fabrics and garments, the meta-aramid fibre is very often used in combination with other fibres that can also contribute for different end use requirements, such as comfort and look. Blends with para-aramid, viscose FR, nylon and antistatic fibres are the most common.

2. The current supply chain

There are two macro categories of products subject to end-of-life treatment. The first are the textile waste that comes from the production of yarns and fabrics, from the processes of clothing cut and sew and unsold stocks. In all these cases we can talk about post-industrial or “pre-consumer” waste.

The other category is that of textile waste after use, so called post-consumer waste. The life average of a piece of protective clothing can vary a lot from case to case. Unlike fashion clothing, which is often placed in charity circuits (organized sales, collections, donations), protective clothing ends on their life cycle in landfills or burnt in thermal incineration plants.

A typical supply chain for protective clothing, with aramid fibres ingredients is described in Annex 1.

In Annex 2 the process flow of recover, recycle, reuse is shown in synthesis.



5. LCA of the textile waste covered by the pilot case

5.1. Life Cycle Assessment: aim and scope

1. Aim

This report presents a summary of Life Cycle Assessment (LCA) conducted on the recycling pilot case of aramid fibres from pre-consumer (or post-industrial) fabric waste. The aim of the pilot is to verify the technical, economic and environmental feasibility of a recovery, recycle and reuse system for professional flame-retardant workwear. The pilot is focused on the following steps: starting from pre-consumer garment waste (i.e. the deadstock), the material goes through a dismantling and a mechanical process to obtain a new yarn from recycled material as final output. Two different sources are considered for the fabric waste in order to have two different types of recycled yarn:

1. CASA A: blue-coloured yarn.
2. CASE B: multicoloured yarn.

The LCA follows the textile material through this path as developed within the pilot and it is aimed at quantifying the potential environmental impacts arising from the process.

5.2. Scope

The LCA starts at the definition of the material entering the system, i.e. the pre-consumer waste. In the pilot, the waste is no more considered as such but it becomes a raw material for another production system. From the LCA point of view, the unsold garments are not accounted as waste but as co-products, and they take part of the environmental burdens generated in the manufacturing process. The figures used to allocate the burdens to products and co-products at the beginning of the system are taken from Koszewska (2018). In this publication, the author reports that 30% of the clothing produced is sold at the recommended retail price, another 30% goes in the sales and 40% remains unsold or do not even reach the shops.

The unsold garments are sent to a dismantling platform. Here, the items are disassembled and their components are separated in order to select the parts considered as suitable to be recycled in the further fraying step. Fraying is a specific mechanical operation that transforms the fabric back to the fibres that can enter the following garneting step. The latter is needed to open and to equalize the fibres, thus preparing it for the carding and spinning processes. The general system is presented in **Figure 1**. The yellow colour indicates the steps included in the system boundaries of the present LCA study.

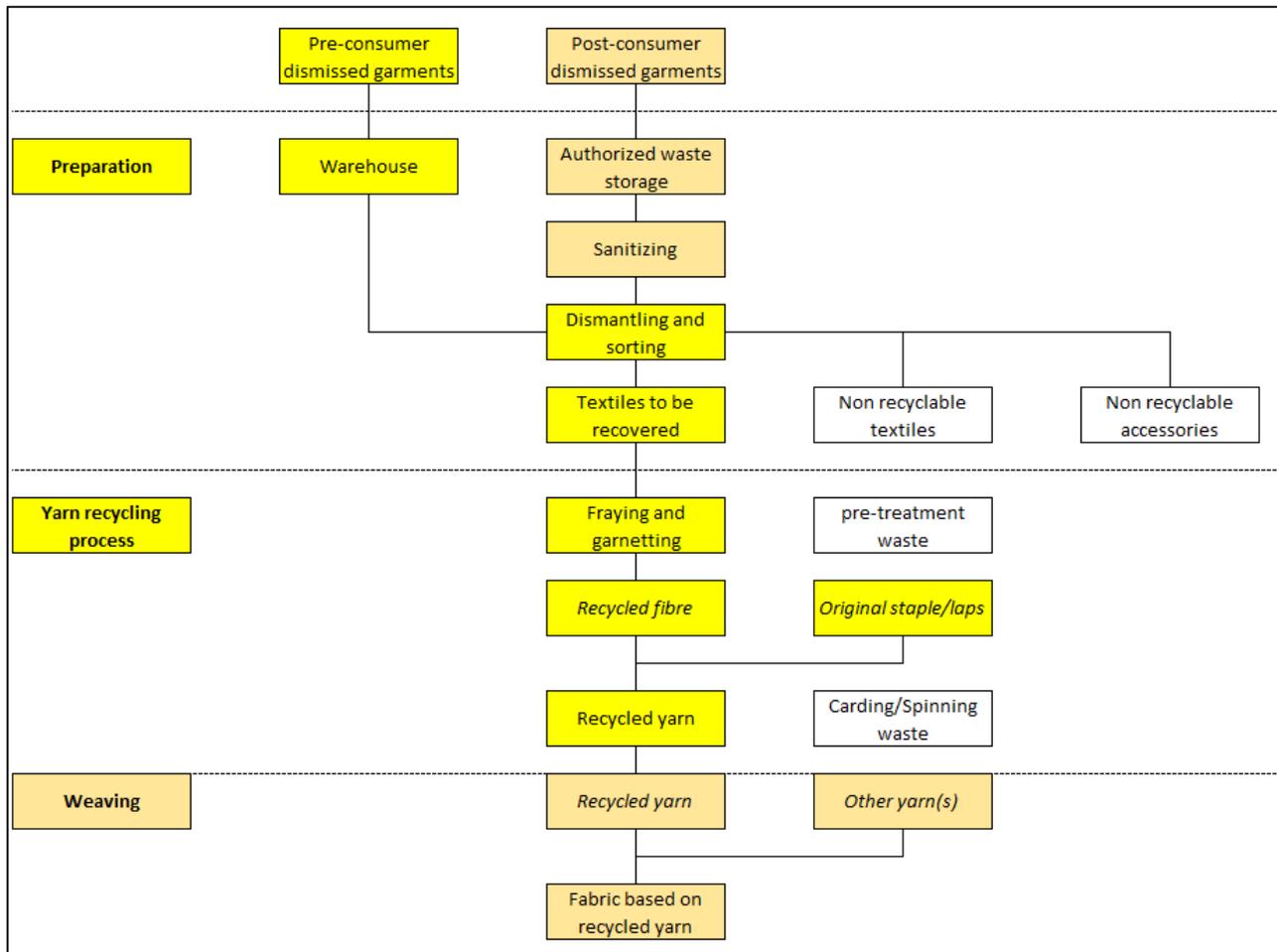


Figure 1 System boundaries (yellow shapes).

The functional unit of the analysis is 1 kg of final output, i.e. recycled or partially recycled yarn (as blue-coloured and as multicoloured).

The environmental impact is calculated by means of the Environmental Footprint method recommended by European Commission when conducting a Product Environmental Footprint (EC, 2013). The version selected is the most updated one (Fazio et al., 2018).

5.3. Life Cycle Inventory

Due to lack of primary data, the fabric production in the first part of the system is based on secondary sources (i.e. the GaBi Professional database, service pack 40¹). Dataset modelling the manufacturing of para-aramid fibre, viscose fabric and polyacrylonitrile fabric were used, complemented by secondary data on auxiliaries (electricity, water, antistatic finishing process).

To model the manufacturing of the unsold garments required some assumptions. In particular, only data about “para-aramid” type was retrieved, then the total amount of aramid fibre was modelled as “para”. Additionally, the fraction of fabric indicated in the composition as “antistatic” (i.e. $\leq 2\%$) was divided between the aramid and viscose (both in CASE A and in CASE B). However, an antistatic finishing process was included in the model, to account for the

¹ <http://www.gabi-software.com/international/databases/gabi-databases/professional/>

necessary inputs. Possible accessories applied to the garments (e.g. zips, buttons, embroideries, labels, etc.) were disregarded due to lack of primary data for modelling their production. However, their mass is considered negligible compared to the total mass of fabrics.

Coming to the recycling process itself, the initial dismantling was modelled only as a transportation. Indeed, no material/energy inputs are required to the process, as it is a manual operation, done by qualified personnel. For the garneting process instead, the energy consumption was included in addition to the transport, and the same was done for the carding and spinning operation.

The transport distances considered in the study are reported in **Table 1**. Transports along the recycling chain are considered as road transports, by means of a truck (Euro 4, gross weight 28 - 34 t).

Table 1 Transport distances as considered in the system.

| ORIGIN-DESTINATION | TRANSPORT MEAN | DISTANCE |
|---------------------------------------|---|----------|
| Maker - Dismantling platform (CASE A) | Truck-trailer, Euro 4, 28 - 34t gross weight / 22t payload capacity | 85 km |
| Maker - Dismantling platform (CASE B) | | 190 km |
| Dismantling platform - Fraying | | 25 km |
| Fraying - Garneting | | 20 km |
| Garneting - Spinning | | 25 km |

For the energy consumed in the recycling steps (i.e. fraying, garneting, carding and spinning), the figures were initially estimated as energy economic cost. An average price for the non-domestic electricity consumption was retrieved from Eurostat statistics (Eurostat, 2019), based on the second semester of 2019. This value for Italy was 0.0931 €/kWh and was assumed to estimate the total energy consumption for the recycling. This initial calculation was a bit overestimated. Primary data were then collected from the company based on the usual consumption of energy (i.e. not strictly referring to the pilot case but deemed more representative). The figures are reported in **Table 2**.

Table 2 Energy consumption per recycling step (economic and electric units).

| RECYCLING STEP | ECONOMIC COST | ENERGY VALUE (ESTIMATED ON THE ECONOMIC COST) | ENERGY VALUE (PRIMARY DATA) |
|----------------------|---------------|---|-----------------------------|
| Fraying | 0.15 €/kg | 5.37 kWh/kg | 0.75 kWh/kg |
| Garneting | 0.30 €/kg | 3.22 kWh/kg | 1.5 kWh/kg |
| Carding and spinning | 0.60 €/kg | 6.44 kWh/kg | 3 kWh/kg |

As specified above, each recycling step is a mechanical treatment, and some losses occur during every process. Therefore, it was necessary to include the related yields in the study, to account for the material losses along the recycling chain. The specific figures for CASE A and CASE B used to model yields and losses are reported in **Table 3**. The low yields are mainly due to the poor



amount of material processed, but according to the material quality and the experience, when scaled up to industrial usual amount, the yields can increase more than 10%.

Table 3 Process yields and material losses along the recycling chain.

| RECYCLING STEP | CASE | YIELD | MATERIAL LOSS |
|----------------------|------|-------|------------------------------|
| Dismantling | A | 91% | 0.09 kg/kg of input material |
| | B | 59% | 0.41 kg/kg of input material |
| Fraying | A | 80% | 0.2 kg/kg of input material |
| | B | 80% | 0.2 kg/kg of input material |
| Garneting | A | 66% | 0.34 kg/kg of input material |
| | B | 63% | 0.37 kg/kg of input material |
| Carding and spinning | A | 61% | 0.39 kg/kg of input material |
| | B | 84% | 0.16 kg/kg of input material |

The material lost during the first step of manual separation is considered as a waste to landfill (a dataset modelling municipal solid waste to landfill in Europe was selected). The material is mixed and mostly composed by accessories (labels, buttons, zip, membranes, plastic hooks, etc). This is an assumption done for reason of simplification within the pilot. Of course, a further analysis is required to evaluate the possible recycle of those parts.

The material lost during fraying, garneting and spinning was considered as textile waste and sent to incineration (a dataset modelling textile waste incineration in Europe was selected).

At the beginning of the carding and spinning process, the input material is blended in order to ensure a regular quality in the final product. For the pilot purposes, the following blending are considered:

- CASE A: 50% material from garneting - 50% recovered laps (navy blue dyed, 100% meta-aramid).
- CASE B: 70% material from garneting - 30% original staple fibre (100% greige meta-aramid).

The recovered laps in CASE A blending come from the processing of virgin aramid fibre and can be both by-products from combing or fragments of staple fibres. To model the blending, the recovered laps were accounted as scraps from the aramid fibre processing: a 5% of scraps were assumed for 1 kg of processed aramid fibre, as an average value.

5.4. Life Cycle Impact Assessment

The goal of the Life Cycle Impact Assessment (LCIA) is to quantify the environmental impacts resulting from the environmental pressures arising from the system analysed. The data calculated in the inventory are converted to “impact scores” according to different indicators. The output of this calculation allows for an in-depth evaluation about the hotspot in the system, i.e. the main



contributors to the impact, and it better shows where to intervene to enhance the environmental performance². The general results for the present pilot are presented as follows:

Quantified impact (Table 4): a selection of indicators recommended for the Product Environmental Footprint and the percentage variation of the impact for each scenario and each impact category.

Resource consumption (Table 5)**Errore. L'origine riferimento non è stata trovata.**: resources consumed in terms of water and energy inputs (both as renewables and non-renewables) and the percentage variation for each scenario and each indicator. Contribution analysis to the total impact (Table 6, Table 7 and Table 8): the percentage contribution of each recycling step is reported together with the fraction of impact avoided (due to the prevented production of virgin aramid fibre).

Table 4 Impact assessment results for the two cases (EF v.3 selected indicators).

| IMPACT INDICATOR | UNIT | CASE A | CASE B | VARIATION |
|----------------------------------|-----------------------------|----------|----------|-----------|
| Acidification | mol H+ eq. | 1,88E-01 | 1,81E-01 | -4% |
| Human Tox, cancer | CTUh | 6,74E-09 | 1,07E-08 | +59% |
| Climate change | kg CO ₂ eq. | 2,59E+01 | 4,25E+01 | +64% |
| Ecotoxicity freshwater | CTUe | 4,53E+02 | 5,32E+02 | +17% |
| Eutrophication, freshwater | kg P eq. | 1,56E-04 | 2,40E-04 | +54% |
| Eutrophication, marine | kg N eq. | 1,46E-02 | 2,38E-02 | +63% |
| Eutrophication, terrestrial | mol N eq. | 1,61E-01 | 2,57E-01 | +59% |
| Ionising radiation | kBq U ²³⁵ eq. | 1,78E+00 | 2,60E+00 | +46% |
| Land use | Pt | 4,67E+02 | 4,38E+02 | -6% |
| Human Tox, non-cancer | CTUh | 2,05E-06 | 1,84E-06 | -10% |
| Ozone depletion | kg CFC-11 eq. | 5,40E-11 | 7,74E-11 | +43% |
| Photochem. ozone formation | kg NMVOC eq. | 4,91E-02 | 7,35E-02 | +50% |
| Resource use, energy carriers | MJ | 4,19E+02 | 7,11E+02 | +70% |
| Resource use, mineral and metals | kg Sb eq. | 7,03E-06 | 1,01E-05 | +44% |
| Particular matter | Disease incidences | 1,57E-06 | 1,53E-06 | -2% |
| Water scarcity | m ³ world equiv. | 3,07E+00 | 3,42E+00 | +12% |

Table 5 Resource consumption results for the two cases.

| RESOURCE INDICATOR | UNIT | CASE A | CASE B | VARIATION |
|-----------------------|----------------|----------|----------|-----------|
| Non-renewable energy | MJ | 4,19E+02 | 7,11E+02 | 70% |
| Renewable energy | MJ | 1,45E+02 | 1,88E+02 | 29% |
| Use of net freshwater | m ³ | 1,63E-01 | 2,36E-01 | 45% |

From the tables above it is clear that the performance of CASE A is slightly better compared to the CASE B (i.e. the average variation is +35%). This is mainly due to the last part of the recycling chain, in the spinning step: in CASE A the recycled yarn is blended together with a recovered fibre that comes from waste material. This feature of the final product generates a higher benefit because of the completed avoiding of producing virgin aramid fibre. This does not happen for CASE

² The values shown in the following tables are reported as the sum of the impact derived from the upstream and downstream.



B, where the final yarn is blended with the original aramid staple fibre, even if in small fraction (i.e. 30%).

These considerations are more evident in the contribution analysis (**Table 6**, **Table 7**). As a general comment, the impact fraction due to the manufacturing of the unsold garments is the more significant. The final spinning of the yarn is the second top contributor, followed by the recycling step (i.e. the mechanical treatments: dismantling, fraying and garneting).

Table 6 Environmental impact: contribution analysis for CASE A (EF v.3 selected indicators).

| IMPACT INDICATOR | TOTAL | PRE-CONSUMER WASTE | GARMENTS RECYCLING | SPINNING OF RECYCLED YARN | AVOIDED IMPACT (VIRGIN ARAMID) |
|----------------------------------|-------|--------------------|--------------------|---------------------------|--------------------------------|
| Acidification | 100% | 98% | 2% | 11% | -10% |
| Human Tox, cancer | 100% | 95% | 5% | 43% | -43% |
| Climate change | 100% | 92% | 7% | 49% | -47% |
| Ecotoxicity freshwater | 100% | 98% | 2% | 25% | -26% |
| Eutrophication, freshwater | 100% | 91% | 6% | 22% | -19% |
| Eutrophication, marine | 100% | 90% | 8% | 39% | -36% |
| Eutrophication, terrestrial | 100% | 90% | 7% | 38% | -35% |
| Ionising radiation | 100% | 85% | 8% | 34% | -26% |
| Land use | 100% | 96% | 2% | 9% | -7% |
| Human Tox, non-cancer | 100% | 100% | 1% | 6% | -7% |
| Ozone depletion | 100% | 100% | 0% | 0% | 0% |
| Photochem. ozone formation | 100% | 93% | 6% | 36% | -34% |
| Resource use, energy carriers | 100% | 97% | 5% | 50% | -52% |
| Resource use, mineral and metals | 100% | 84% | 9% | 41% | -33% |
| Particular matter | 100% | 99% | 1% | 10% | -10% |
| Water scarcity | 100% | 51% | 20% | 27% | -3% |

Table 7 Environmental impact: contribution for CASE B (EF v.3 selected indicators).

| IMPACT INDICATOR | TOTAL | PRE-CONSUMER WASTE | GARMENTS RECYCLING | SPINNING OF RECYCLED YARN | AVOIDED IMPACT (VIRGIN ARAMID) |
|-------------------------------|-------|--------------------|--------------------|---------------------------|--------------------------------|
| Acidification | 100% | 96% | 2% | 5% | -3% |
| Human Tox, cancer | 100% | 91% | 4% | 13% | -8% |
| Climate change | 100% | 87% | 7% | 14% | -9% |
| Ecotoxicity freshwater | 100% | 94% | 2% | 10% | -7% |
| Eutrophication, freshwater | 100% | 83% | 13% | 7% | -4% |
| Eutrophication, marine | 100% | 89% | 6% | 11% | -7% |
| Eutrophication, terrestrial | 100% | 90% | 6% | 11% | -7% |
| Ionising radiation | 100% | 87% | 6% | 12% | -5% |
| Land use | 100% | 94% | 2% | 5% | -2% |
| Human Tox, non-cancer | 100% | 98% | 1% | 3% | -2% |
| Ozone depletion | 100% | 100% | 0% | 0% | 0% |
| Photochem. ozone formation | 100% | 90% | 5% | 11% | -7% |
| Resource use, energy carriers | 100% | 92% | 3% | 14% | -9% |



| IMPACT INDICATOR | TOTAL | PRE-CONSUMER WASTE | GARMENTS RECYCLING | SPINNING OF RECYCLED YARN | AVOIDED IMPACT (VIRGIN ARAMID) |
|----------------------------------|-------|--------------------|--------------------|---------------------------|--------------------------------|
| Resource use, mineral and metals | 100% | 86% | 6% | 15% | -7% |
| Particular matter | 100% | 96% | 2% | 5% | -3% |
| Water scarcity | 100% | 64% | 19% | 16% | -1% |

The results presented above highlight the decreasing of the avoided impact in CASE B. As already mentioned, this is mainly caused by the use of virgin aramid staple fibre in the spinning process in order to ensure an adequate level of quality for the output. Nevertheless, an average -5% impact is registered for this case study, even if significantly lower compared to the one recorded for case A (i.e. an average -25%).

The same result is reported when the resource indicators are investigated (**Table 8**). Here, the highest saving occur in the energy consumption: cumulatively, -76% for Case A and -15% for Case B. Concerning the other parts of the system, the manufacturing of the unsold garments (pre-consumer waste) contribute the most to the impact, even if allocated. On the other hand, the recycling mechanical steps (i.e., dismantling, fraying and garneting) have a general low contribution, even if the yield of the process are not optimized and there is room for improvement.

Table 8 Resource consumption: contribution analysis for Case A and Case B.

| RESOURCE INDICATOR | TOTAL | PRE-CONSUMER WASTE | GARMENTS RECYCLING | SPINNING OF RECYCLED YARN | AVOIDED IMPACT (VIRGIN ARAMID) |
|-----------------------|-------|--------------------|--------------------|---------------------------|--------------------------------|
| CASE A | | | | | |
| Non-renewable energy | 100% | 97% | 5% | 50% | -26% |
| Renewable energy | 100% | 80% | 9% | 35% | -12% |
| Use of net freshwater | 100% | 82% | 10% | 41% | -17% |
| CASE B | | | | | |
| Non-renewable energy | 100% | 92% | 3% | 14% | -9% |
| Renewable energy | 100% | 83% | 8% | 15% | -6% |
| Use of net freshwater | 100% | 85% | 7% | 15% | -7% |

5.5. References

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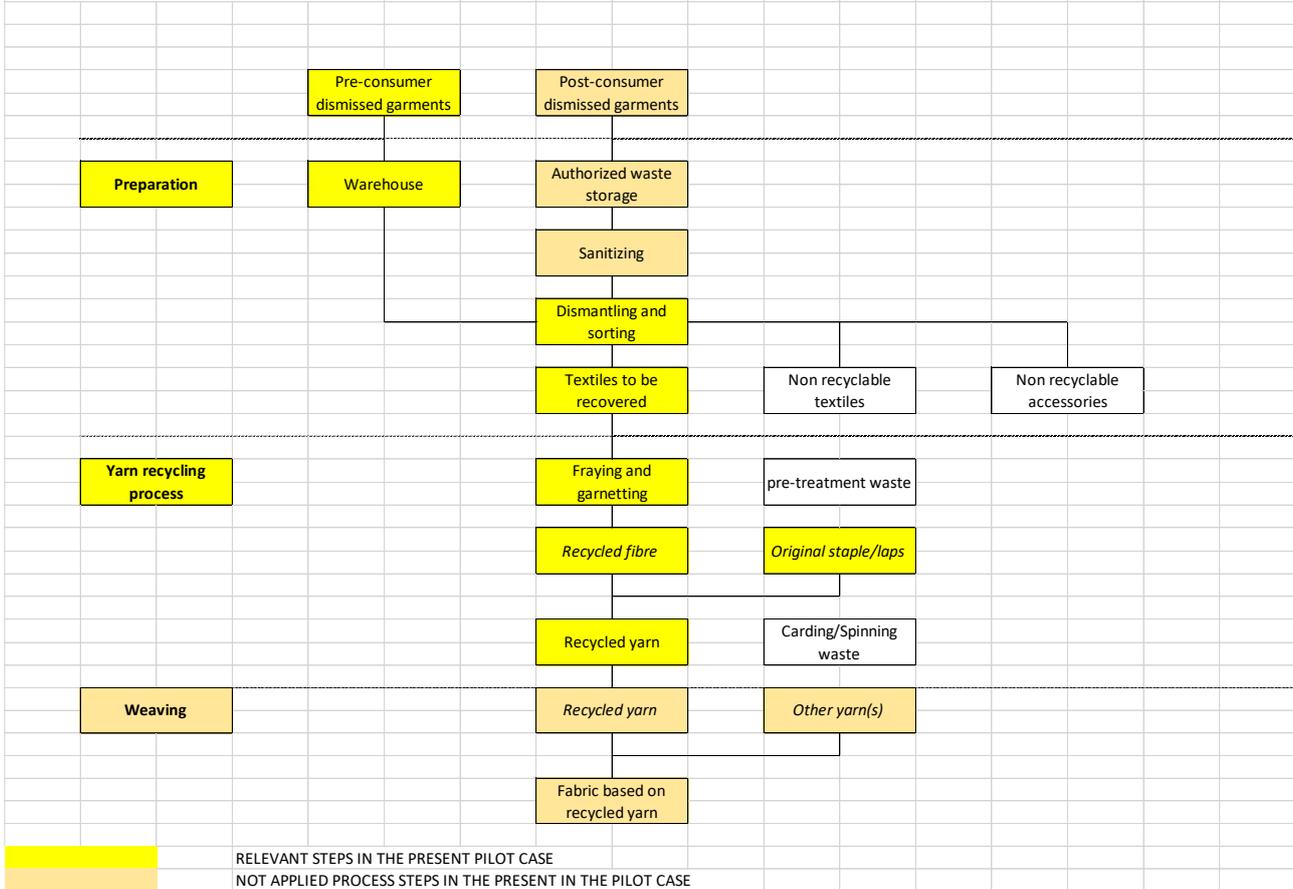
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6. Annex 1

Annex 1

PILOT CASE - PRODUCTION OF RECYCLED ARAMID YARN FROM PRE-CONSUMER PROFESSIONAL GARMENTS

EXAMPLE OF RECOVER / RECYCLE / REUSE PROCESS





7. Annex 2

| Annex 2 | | | | | | | | | | | |
|--|---|------------------------------|-------------|-------------|-------------|--|-------------|-------------|-------------|--|--|
| PILOT CASE - PRODUCTION OF RECYCLED ARAMID YARN FROM PRE-CONSUMER PROFESSIONAL GARMENTS | | | | | | | | | | | |
| MASS BALANCE | | | | | | | | | | | |
| | | pilot project - real figures | | | | pilot project - estimate industrial scenario | | | | | |
| | | CASE A | % vs. tot. | CASE B | % vs. tot. | CASE A | % vs. tot. | CASE B | % vs. tot. | | |
| | | Kg | % | Kg | % | Kg | % | Kg | % | | |
| | TOTAL INPUT | 16,7 | 100% | 34,8 | 100% | 1000 | 100% | 1000 | 100% | | |
| DISMANTLING AND SELECTION | outer layer | 15,2 | 91% | 8,2 | 24% | 910 | 91% | 236 | 24% | | |
| | inner layer | | | 12,2 | 35% | | | 351 | 35% | | |
| | PU membrane | | | 2,9 | 8% | | | 84 | 8% | | |
| | accessories (h&l, zips, buttons, labels,...) | 1,5 | 9% | 11,5 | 33% | 90 | 9% | 330 | 33% | | |
| FRAYING | input | 15,2 | 100% | 20,4 | 100% | 910 | 100% | 586 | 100% | | |
| | waste | 3 | 20% | 4 | 20% | 55 | 6% | 35 | 6% | | |
| | output | 12,2 | 80% | 16,4 | 80% | 855 | 94% | 551 | 94% | | |
| GARNETTING | input | 12,2 | 100% | 16,4 | 100% | 855 | 100% | 551 | 100% | | |
| | waste | 4,2 | 34% | 6 | 37% | 100 | 12% | 65 | 12% | | |
| | output | 8 | 66% | 10,4 | 63% | 755 | 88% | 486 | 88% | | |
| CARDING AND SPINNING | input recycled material | 8 | | 10,4 | | 755 | 70% | 486 | 70% | | |
| | input staple/laps | 3,5 | 30% | 4,5 | 30% | 330 | 30% | 210 | 30% | | |
| | total input blend | 11,5 | | 14,9 | | 1085 | | 696 | | | |
| | waste | 4,5 | 39% | 2,4 | 16% | 109 | 10% | 70 | 10% | | |
| | TOTAL OUTPUT | 7 | | 12,5 | | 977 | | 627 | | | |