Environmental impact assessment of the post-consumer recycled denim life cycle 'from cradle to gate'

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1. Study Overview

Input data: Primary data, wherever possible

Scope: From raw material to fabric (weaving, dyeing, finishing)

Database used: Ecoinvent 3.7.1

Functional unit: 1 kg di Denim Post Consumer Recycled (KR7228RG K-NEW GRAND CRU), produced da Candiani S.p.A.

Reference product: 1 kg of 'Standard Denim', from raw material to finished fabric (cultivation, ginning, spinning, weaving, dyeing, finishing).

2. Study Scope

The purpose of this study is to evaluate the environmental impact associated with the production of Post Consumer Recycled denim (KR7228RG K-NEW GRAND CRU), from raw material to finished fabric (spinning, weaving, dyeing, finishing), using 'regenerative' cotton (RG) produced in Spain by Algosur S.A (transported by ECOM AGROINDUSTRIAL CORP. LTD) and Post Consumer Recycled (PCR) denim supplied by Humana People to People Italia and processed by Filatura Astro S.r.l. As a reference, a similar fabric produced with conventional technologies was considered, namely standard denim produced from cotton grown and processed globally with production processes mainly located in Asia and the United States.

3. The Function and Functional Unit Selected

The function considered was the production of the two fabrics under examination; the properties of the two products find practical applications (e.g., type of use, mechanical strength, aesthetic yield, and durability) that can be considered equal and are therefore ideal for comparing their respective environmental impacts. As a functional unit, one kilogram of fabric downstream of the finishing process and ready to be shipped to customers (cradle to gate) was chosen. This means that material and energy flows were collected referring to the fixed quantity for both products.

4. System Boundaries

With a desire to conduct a comprehensive investigation of the issue, all preliminary processes related to the production of the denim in question have been considered: this means that all aspects related to the procurement of raw materials and the supply of energy and water have also been analyzed. The material and energy flows affecting the examined system have been evaluated and classified based on their environmental impact: depending on the case, they can either impoverish or enrich the external environment. In the former case, the environment acts as a reservoir (e.g., use of groundwater), while in the latter case, it acts as a discharge system (e.g., emissions of CO_2 into the atmosphere). The boundaries of the system are considered to be those of the companies where the individual processes are carried out, as schematized in Figure 4.1 for the Denim Standard and in Figure 4.2 for the Denim Post Consumer Recycled.

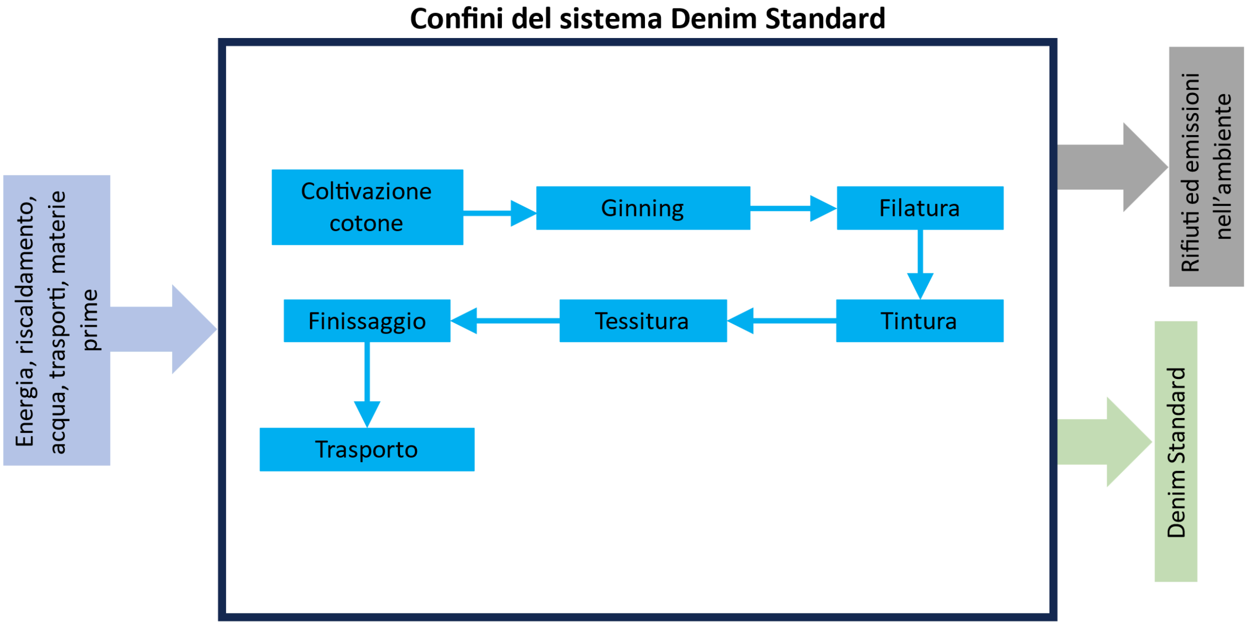

Figura 4.2: Schema relativo ai confini del sistema analizzato per la produzione di Denim Standard

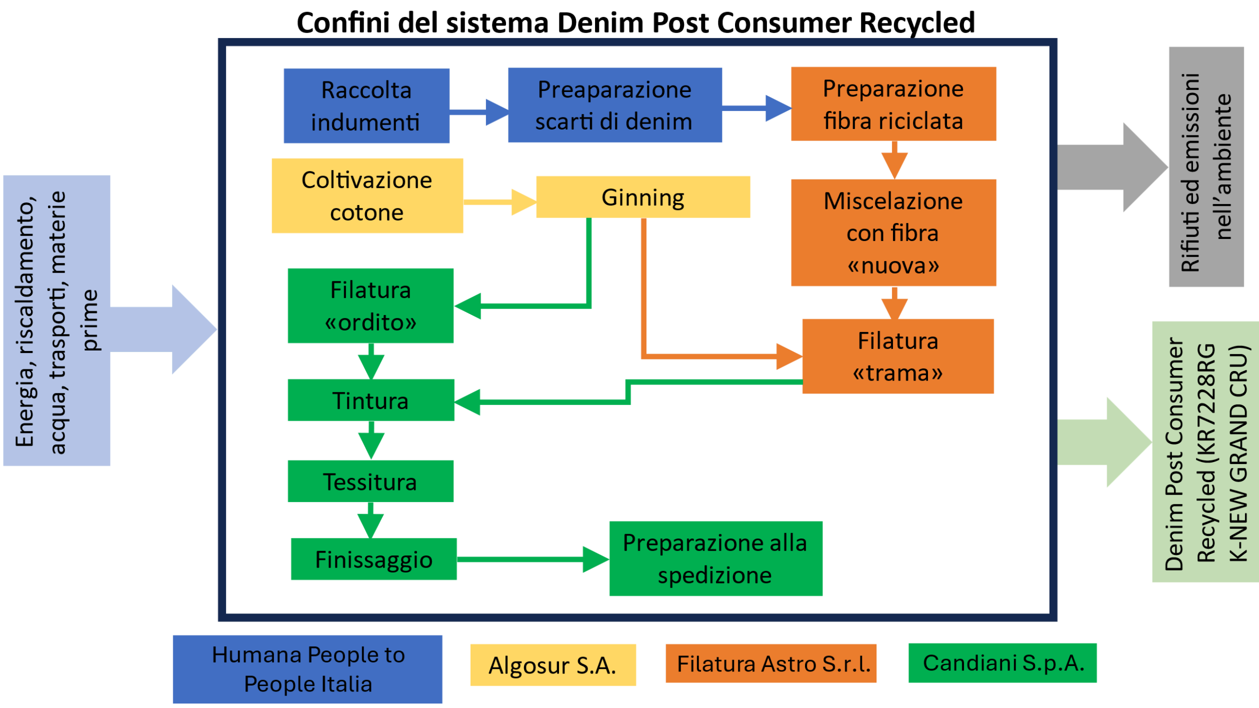

Figure 4.1: Diagram relating to the system boundaries analyzed for the production of Post-Consumer Recycled Denim, indicating the companies managing the various phases of the process

To define the boundaries of the system, it was necessary to establish certain conditions; these are described below:

Cut-off criteria

In this study, no material flows were cut: all flows necessary for the investigation were considered in their entire path (from the input to the output of the system), provided that the data were sufficient. For data relating to emissions not estimable from the collected data, emission factors of the most similar processes in the Ecoinvent 3.7.1 database were used.

Allocation

The total impacts of the process were divided among the individual subprocesses, based on the role each of them played in the supply chain. Likewise, values related to emissions and disposals connected to the production process were treated: in this case, too, a division was made, taking into account the various contributions.

Geographical and chronological references

To evaluate the reference product (Standard Denim), global average processes (GLO) were considered, where different technologies and producing countries are weighted according to their global production relevance for each process.

For the evaluation of the studied product (Denim Post Consumer Recycled), the calculations refer to the country where the individual process takes place. This includes Italy for processes managed by Candiani S.p.A., Filatura Astro S.r.l., ECOM AGROINDUSTRIAL CORP. LTD, and Humana People to People Italia, while Spain was used for ginning by Algosur S.A. For all processes and materials for which specific information for the countries in question was not available, the RER (Europe) geographical area was used first, if not available, RoE (Rest of Europe), RoW (Rest of the World), or GLO (Global).

The reference year for all evaluations was chosen as 2023.

5. Methodology

Endpoint ReCiPe 2016 v1.1, hierarchical perspective (H).

This is the default ReCiPe endpoint method. The ReCiPe 2016 method is a new version of ReCiPe 2008, created in the Netherlands through collaboration between the National Institute for Public Health and Environment (RIVM), Radboud University Nijmegen, Leiden University, and PRé Sustainability company. The method includes global normalization factors for the reference year 2010.

Figure 5.1 shows the impact categories (midpoint) considered by this method and their relationship with the protection areas (endpoint). The impact categories (midpoint) will be used to identify the most critical aspects, while subsequent assessments will be based on overall impacts (endpoint).

The life cycle of a product is associated with a very large number of substance emissions and the use of various resources that may have different levels of environmental relevance. Life cycle impact assessment translates these emissions and resource extractions into a limited number of environmental impact scores. This is done through so-called characterization factors that quantify the environmental impact per unit of stress factor (e.g., amount of resources used or emissions released).

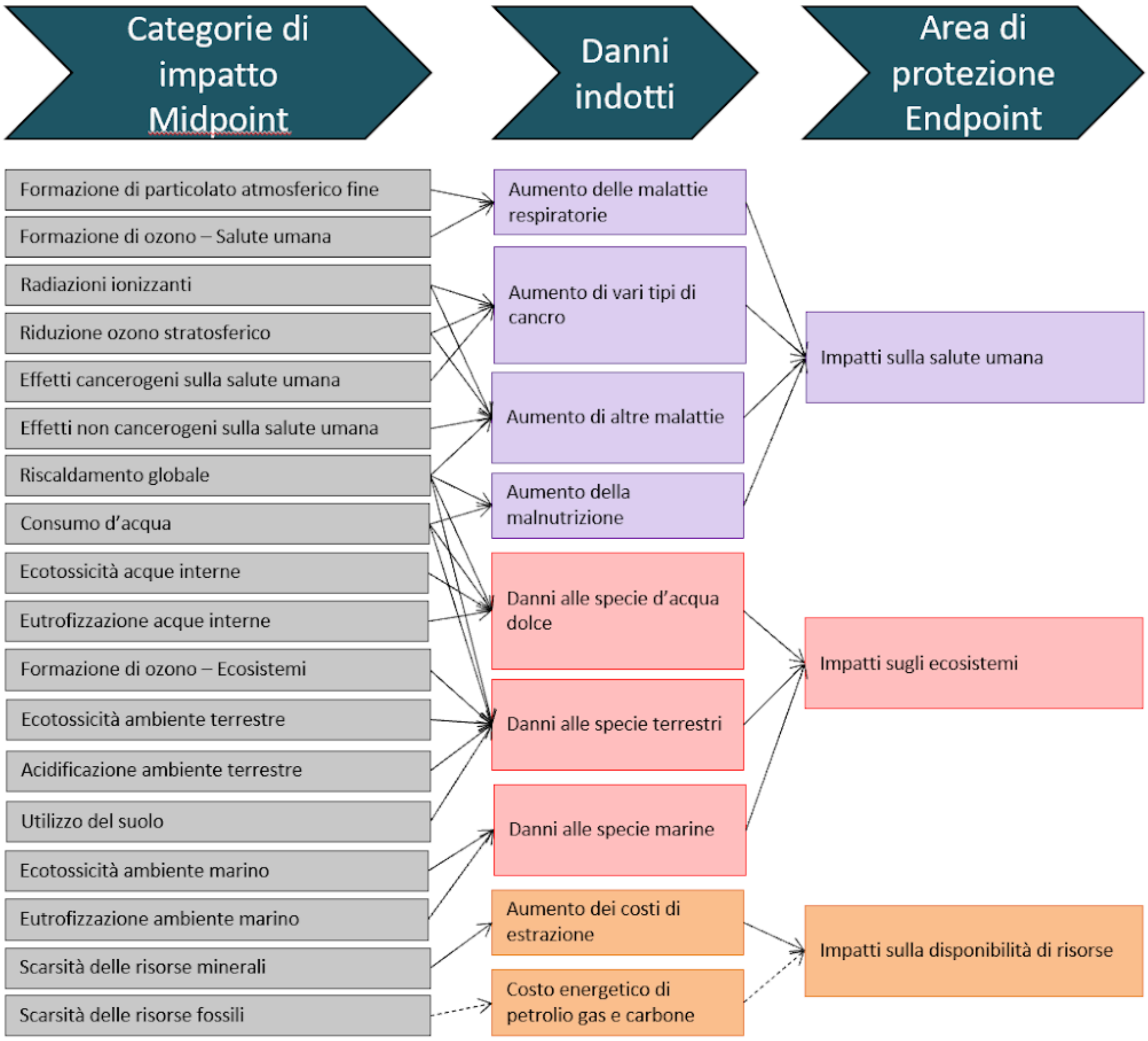

Figure 5.1 - Overview of the impact categories (midpoint) covered by the ReCiPe2016 methodology and their relationship with the protection areas (endpoint).

Human health, ecosystem quality, and resource scarcity have been selected as three protection areas (or endpoints) for implementing the ReCiPe2016 methodology. The unit of measure for human health damage is DALY (Disability Adjusted Life Year), representing the years a person becomes disabled due to illness or accident. The unit of measure for ecosystem damage is the loss of local species over time (number of species lost per year). The unit of measure for resource scarcity is the dollar ($) and represents the additional costs required for future extraction of mineral and fossil resources. The process leading to the calculation of these indicators is called normalization. The relative importance of the different endpoints is attributed to the weighting phase to obtain comparable values. In this study, the weighting coefficients of the hierarchical perspective (H) were used to obtain Pt (Impact Points) which allow quantification and comparison of impacts on the three endpoints considered. For all assessments, infrastructure impacts, and long-term emissions (>100 years) were excluded.

6. Inventory Analysis

6.1 Standard Denim

To assess the impacts of the reference product (Denim Standard), the information available in the Ecoinvent 3.7.1 database was used. A schematic representation of the processes involved and their respective impacts is shown in Figure 6.1.

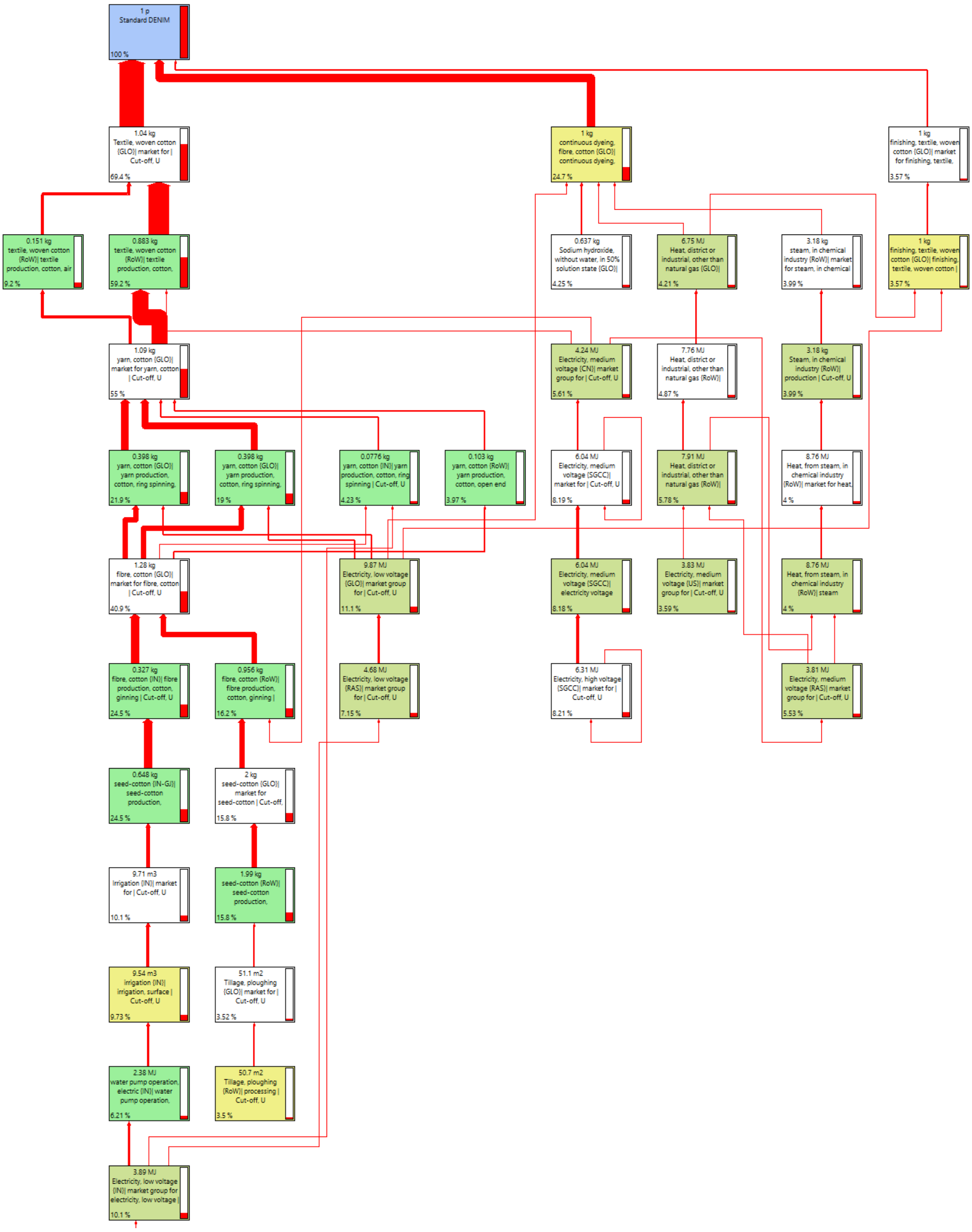

Figure 6.1 - Schematic representation of the main energy and material flows related to the production of 1 kg of Denim Standard, from raw material to fabric, through the stages of spinning, weaving, dyeing, and finishing using the information available in the Ecoinvent 3.7.1 database. The relative contribution of each process is shown in %. Processes with a contribution of less than 3.5% have been excluded.

In the graph shown in Figure 6.1, the thickness of the arrows indicates the magnitude of the impact due to the various processes. The same information is reported as a percentage in the bottom left corner of the boxes related to individual processes. The information shown at the top center of each box refers instead to the quantity of materials/energy/services per functional unit, necessary for the production of 1 kg of Standard Denim.

The production of cotton fabric, schematized in the left area of the graph, represents the most complex process and causes the greatest impact. The impacts increase gradually between the various stages of the cotton fabric production process (cultivation, ginning, spinning, and weaving), and there is no clearly critical phase from an environmental perspective. The impacts of the dyeing process, represented in the center of the graph, are largely related to the use of chemicals and, to a lesser extent, to electricity consumption, heating, and steam production. The finishing process, represented in the right area of the graph, has the lowest impact among the three processes considered and is mainly related to electricity consumption and heating.

6.1.1 Cotton Fabric Production

For the fabric production process, data from Ecoinvent 3.7.1 were used, collected from companies globally located in India, Bangladesh, China, and the United States. The process begins with cotton cultivation (traditional agriculture) and ginning, which generally occur within the same company.

For the cultivation phase, the use of land, soil processing, irrigation, seed usage and production, fertilizers, pesticides, growth hormones, and all emissions resulting from these operations are considered. The process ends with the collection of cotton seeds.

For the ginning process, which involves processing 2.08 kg of cotton seeds to obtain 1 kg of fibers, energy consumption (electricity and heat production) was considered.

Spinning is generally located in the same country as cotton cultivation but by different companies. The most commonly used technology is traditional (Ring) (75%), but Open End technology is also used (in the remaining 25% of cases).

Similarly, weaving is generally located in the same country as yarn production but by different companies. The most commonly used technology is air-jet looms (85%), but traditional technology is still applied in 15% of cases.

The cultivation and ginning, spinning, and weaving processes include transportation between processing sites, mainly located within the same country. Transportation by air, sea, and road is considered.

Data related to the production of 1.097 * 10^12 kg of cotton fabric were used and subsequently normalized to the production of 1 kg.

Emissions in the different sectors were evaluated based on the data present in the Ecoinvent 3.7.1 database.

The items considered in the balance are:

Input:

- Land use;
- Soil processing activities;
- Chemicals;
- Water;
- Transport of material between the various companies involved;
- Electricity;

- Heating.

Output:

- Product: cotton fabric;
- Intermediate products: cotton seeds, cotton fibers, cotton yarn;
- Waste: wastewater, emissions to soil, air emissions, undifferentiated solid waste, yarn, and fabric scraps.

6.1.2 Continuous Dyeing Process: Cotton Fabric

For the cotton fabric dyeing process, data from Ecoinvent 3.7.1 were used, collected from companies globally. The process includes the pretreatment of raw cotton fabric before dyeing, and the dyeing itself. It involves the use of electricity, heating, and chemicals.

Data related to the dyeing of 7 * 1010 kg of cotton fabric were used, and subsequently normalized to the functional unit. To account for losses, the functional unit was corrected to 1.04 kg of fabric.

Emissions into water were evaluated based on primary data and supplemented with default data, considering wastewater treatment.

The items considered in the balance are:

Input:

- Cotton yarn
- Transport to the processing site;
- Chemical products;
- Water;
- Electricity;
- Heating;
- Steam.

Output:

- Product: dyed cotton fabric;
- By-products: other recycled/reused garments, allocation based on mass 99.5%.
- Waste: wastewater, emissions into the soil, undifferentiated solid waste, yarn, and fabric scraps.

6.1.3 Finishing Process: Cotton Fabric

For the finishing process of the fabric, data from Ecoinvent 3.7.1 were used, collected from companies globally. The cotton fabric is treated after dyeing, and the finished fabric ready for shipping is produced. The process includes the use of electricity, chemicals, heating and water.

Data related to the finishing of 3.77 * 10^10 kg of cotton fabric were used and subsequently normalized to the functional unit of 1 kg. Unlike the previous phase, no losses are expected during processing.

The items considered in the balance are:

Input:

- Cotton fabric after the dyeing process;
- Transportation to the processing facility;
- Chemicals;
- Water;
- Electricity;
- Heating.

Output:

- Product: Cotton fabric ready for shipping;
- Waste: wastewater, emissions into the soil, undifferentiated solid waste, yarn, and fabric scraps.

6.1.4 Transport of the Finished Product

For the transportation process, data from Ecoinvent 3.7.1 were used, collected from companies on a global scale. The process involves shipping by sea from the production area (Asia or the United States) to the user area (Europe). The process begins with loading the material into the container and ends with the delivery of the material to the destination port. This process includes the use of the ship, container, diesel consumption, and port activities.

Data related to the transportation of 3.7 * 10^13 tkm (tons per kilometer) were used, and subsequently normalized to the functional unit, in this case, the transportation of 1 kg per 1 km. A transportation distance of 20,000 km was assumed for supply to the European market.

The items considered in the balance are:

Input:

- Maintenance of cargo ship;
- Maintenance of container;
- Diesel fuel;
- Electricity;
- Heating.

Output:

- Product: transportation of goods;
- Waste: air emissions, water emissions, bilge oil.

6.2 Post Consumer Recycled Denim

To assess the impacts of the studied product (Post Consumer Recycled Denim), the information provided by the companies involved in the process was used and supplemented with data available in the Ecoinvent 3.7.1 database. A schematic of the processes involved and their respective impacts is shown in Figure 6.2. In this graph, green arrows represent avoided impacts, while red arrows indicate impacts on the environment. The thickness indicates the extent of the impact of the various processes. The same information is presented as a percentage in the bottom-left corner of the boxes related to individual processes. The information displayed at the top center of each box refers instead to the quantity of materials/energy/services necessary per functional unit, i.e., for the production of 1 kg of Post-Consumer Recycled Denim.

The impacts of cotton yarn production PCR/RG are offset by the impacts avoided by recycling material, as indicated by the green arrows, and the impact percentages associated with this phase of the process are negative. The textile production processes, particularly yarn production from regenerative cotton and subsequent weaving, are more impactful than the subsequent phases (dyeing and finishing).

Textile production, schematized in the center-left area of the graph, is the most complex process and causes the most significant impacts. The impacts caused by cotton cultivation are higher than those related to subsequent phases (ginning, spinning, and weaving) and represent 42% of the total impacts. The impacts of PCR/RG cotton yarn production (in the center of the graph) are offset by the impacts avoided through raw material recycling, as indicated by the green arrows and negative impact percentages. The impacts of dyeing and finishing processes, represented in the right area of the graph, account for less than 20% overall and are mainly related to the use of chemicals and electricity. The energy used for heating, whose production process is represented in the center of the graph, causes significant environmental impacts, comparable to those of the dyeing phase.

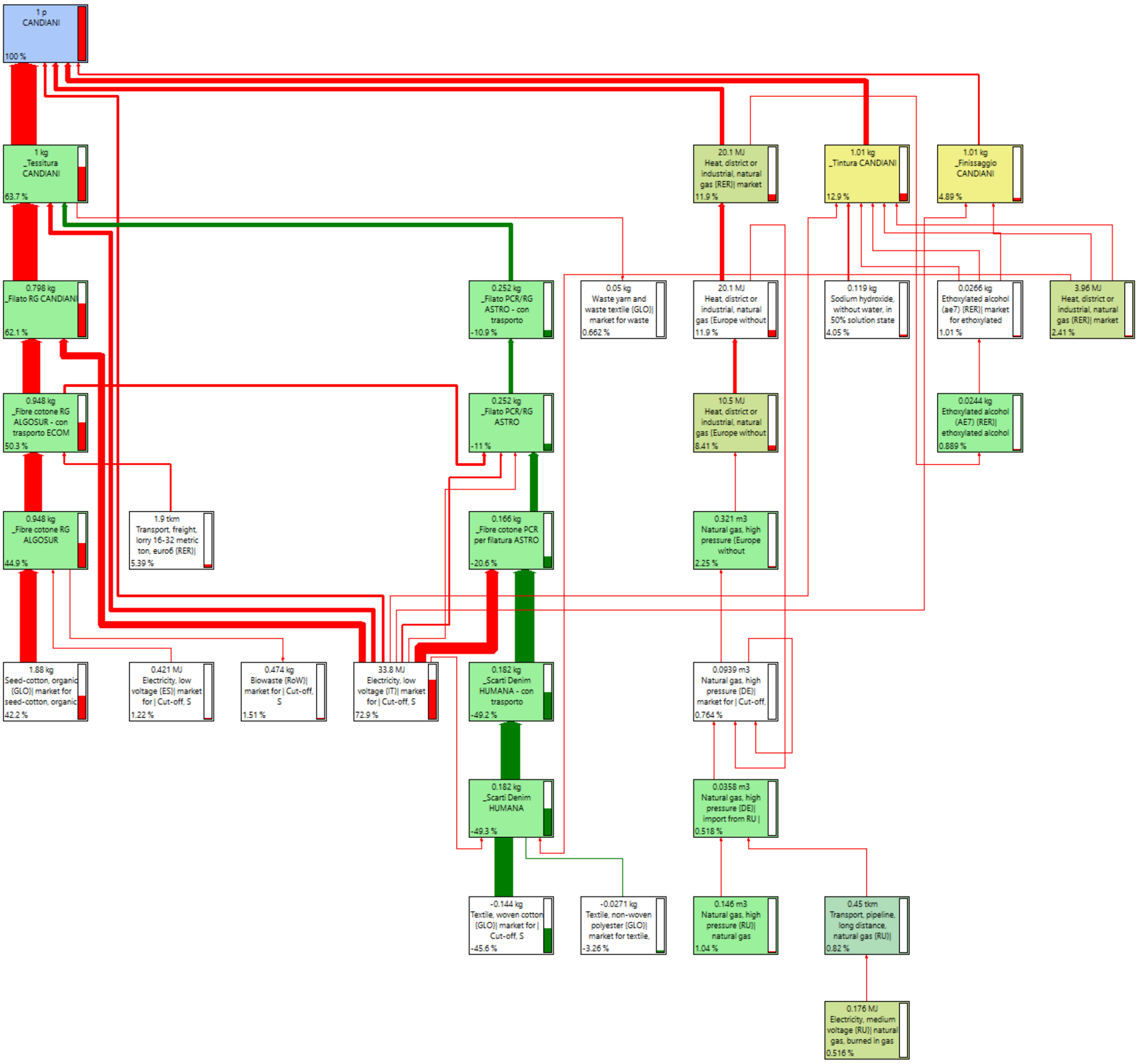

Figure 6.2 - Schematic representation of the main energy and material flows related to the production of 1 kg of PCR denim, from raw material to fabric including spinning, weaving, dyeing, and finishing using the information provided by the supply chain or available in the Ecoinvent 3.7.1 database. The relative impact of each process is expressed as a percentage. Processes contributing less than 0.50% have been excluded.

6.2.1 The Cultivation and Ginning of Long Staple Cotton (RG)

For the cultivation and ginning process, data from Ecoinvent 3.7.1 were used, collected from companies globally located in India, Bangladesh, China, and the United States. Energy consumption was entirely attributed to the Spanish market given the location of the producing company (Algosur S.A.).

Since data on the cultivation of long-fiber regenerative cotton (RG) are not available in the Ecoinvent database, data related to cotton produced through organic farming were chosen. The process begins with the cultivation of RG cotton (organic farming) and the ginning, which in this case takes place on the same farm.

The cultivation phase includes land use, soil processing, seed and compost use and production, and all resulting emissions. The process ends with the collection of cotton seeds. For the ginning process, energy consumption was considered equal to that available in the Ecoinvent database, while Spain was considered the sole country of use instead of the mix of countries used to characterize the process on a global scale. The process involves processing 1.98 kg of cotton seeds to obtain 1 kg of fibers. The process includes transportation for 2,000 km from the processing site (Lebrjia, ES) to Candiani S.p.a. (Robecchetto con Induno, IT).

Data related to the production of 1.23 * 10^8 kg of organic cotton fibers (RG) were used, normalized to the production of 1 kg (functional unit) of the finished product.

Emissions in the various compartments were evaluated based on primary data and supplemented with default data for the creation of the Ecoinvent database and were not modified for this study.

The items considered in the balance are:

Input:

- Land use;
- Soil processing activities;
- Compost;
- Water;
- Electricity;
- Transportation of materials from the processing site to Candiani S.p.a. (data provided by ECOM AGROINDUSTRIAL CORP. LTD).

Output:

- Final product: RG cotton fibers;
- Waste: wastewater, emissions into the soil, air emissions, non-segregated solid waste, and organic waste.

6.2.2 Collecting and Processing “Denim Scraps”

For the process of collecting and processing denim scraps, data provided by HUMANA PEOPLE TO PEOPLE ITALIA were used. The process begins with the collection of recyclable garments and their delivery to the processing site, where they are first sanitized and then separated based on the material and subsequent destination. Denim scraps represent less than 1% of the total production. Before shipment, all metal parts are removed from the denim scraps using an industrial cutter.

Data related to the production of 9,800 kg of denim scraps were used and subsequently normalized to the production of 1 kg of finished product.

The items considered in the balance are:

Input:

- Transportation of materials from collection points to the processing site;
- Chemicals (Ozone for disinfection);
- Electricity;
- Heating;
- Transportation of materials from the processing site to Filatura Astro S.r.l.

Output:

- Product: denim scraps, mass-based allocation 0.5%;
- By-products: other recycled/reused garments, mass-based allocation 99.5%;
- Waste: solid waste, partly recycled, partly incinerated, air emissions;

Avoided products: Cotton (fibers and fabric), polyester (fabric), polypropylene (fabric).

6.2.3 Spinning Process: PCR/RG Cotton

For the spinning process, data provided by Filatura Astro S.r.l. was used. The process begins with the processing of denim scraps, which are shredded (with a loss of about 10%) to be used for subsequent Open End spinning with RG cotton fibers in a 60/40 ratio (with a further loss of about 10%). From the scraps of these processes, sub-carding (1%) is generated, sold, and reused to produce batts.

Data related to the production of 21,485 kg of PCR/RG yarn were used and subsequently normalized to the production of 1 kg of finished product.

The items considered in the balance are:

Input:

- Water;
- Electricity;
- Heating;
- Chemicals;
- RG cotton fibers;
- PCR denim scraps;
- Transport of material from the processing plant to Candiani S.p.a.

Output:

- Final product: PCR/RG yarn, allocated on a mass basis of 99%;
- By-products: Sub-carding resold for reuse, allocated on a mass basis of 1%;
- Waste: Textile waste, wastewater, air emissions.

6.2.4 Spinning Process: RG Cotton

For the RG cotton spinning process used in the warp, data provided by Candiani S.p.a. were used. The process involves spinning RG cotton using ring spinning technology.

Data related to the production of 25,163 kg of RG yarn were used and then normalized to the production of 1 kg of finished product.

The items considered in the balance are:

Input:

- Electricity
- RG cotton fibers
- Transportation of materials internally within the processing facility at Candiani S.p.a.

Output:

- Final product: PCR/RG yarns
- Waste: cotton fibers and yarn.

6.2.5 Dyeing Process: PCR/RG Yarns

For the dyeing process, data provided by Candiani S.p.a. were used. The process begins with raw cotton yarn that are pre-treated before dyeing and ends with dyed cotton yarns. It includes the use of electricity, water, heating, and chemicals.

Data related to the dyeing of 972 kg of PCR/RG denim was used and subsequently normalized to 1 kg of dyeing. The process is to be used with 1.01 kg of fabric to account for losses.

Items considered in the balance are:

Input:

- Water
- Electricity
- Methane gas energy
- Chemicals
- PCR/RG yarns

Output:

- Product: Dyed PCR/RG yarns
- Waste: yarn waste, wastewater, air emissions.

6.2.6 Weaving Process: PCR/RG Denim

For the weaving process, data provided by Candiani S.p.a. were used. The process involves weaving with projectile looms using the yarns described in paragraphs 6.2.3 and 6.2.4.

During the weaving process, 76% RG cotton yarn and 24% PCR/RG yarn are used. To produce 1 kg of fabric, 1.05 kg of yarn is needed.

Data related to the weaving of 37,281 kg of PCR/RG denim were used and then normalized to the weaving of 1 kg. The process should account for 1.05 kg of yarn to consider losses. Emissions in different sectors related to the use, wear, and maintenance of the looms were evaluated using data on air-jet technology, as projectile technology is not available in the Ecoinvent database.

The items considered in the balance are:

Input:

- Electricity;
- RG cotton fibers
- PCR/RG cotton yarns
- Transportation of materials internally within the processing facility at Candiani S.p.a.

Output:

- Product: finished PCR/RG denim;
- Waste: textile waste, wastewater, air emissions.

6.2.7 Finishing Process: PCR/RG Denim

For the finishing process, data provided by Candiani S.p.a. were used. The process starts with the cotton fabric after the dyeing process and ends with the cotton ready for shipment. It includes the use of electricity, water, heating, and chemicals.

Data related to the finishing of 37,281 kg of PCR/RG denim were used and then normalized to the finishing of 1 kg. The process should account for 1.01 kg of fabric to consider losses.

The items considered in the balance are:

Input:

- Water
- Electricity
- Energy from methane gas
- Chemicals
- PCR/RG denim after dyeing

Output:

- Product: finished PCR/RG denim
- Waste: textile waste, wastewater, air emissions

6.2.8 Assembly: PCR/RG Denim

For the process of collecting and processing denim scraps, data provided by Candiani S.p.a. were used. It was necessary to include this phase to account for consumption not attributable to any of the other processes managed by Candiani S.p.a. illustrated previously (e.g., electricity and heating consumption for office areas). For the reference product, this information is already divided among the individual processes. No transports for the finished product were considered as the production and consumption areas coincide.

Data related to the production of 37,281 kg of PCR/RG denim were used and subsequently normalized to the production of 1 kg of finished product.

The items considered in the balance are:

Input:

- Water;
- Electricity;
- Heating;
- Finished PCR/RG denim.

Output:

- Product: Finished PCR/RG denim, ready for shipment;
- Waste: Textile waste, wastewater, air emissions.

7 Impacts

7.1 Standard Denim

The most relevant impact categories were found to be those related to global warming, the formation of fine atmospheric particulate matter, and the release of substances with non-carcinogenic effects on human health (Figure 7.1).

Figure 7.1 - Impacts of the production of the reference product (Denim Standard), in Pt (impact points), divided by impact categories.

Other significant impacts are represented by land and water consumption, as well as the effects of global warming on terrestrial ecosystems. For all impact categories considered, the most significant process is the production of the fabric, except for non-carcinogenic effects on human health, where the dyeing process accounts for almost 70% of the impacts.

Considering the impacts related to each of the three endpoints considered (Human Health, Ecosystems, Resources), fabric production is the process that causes the greatest environmental impacts for all endpoints considered, ranging from 65% to 90%, while the contribution of the dyeing phase is approximately 10-30% (Figure 7.2).

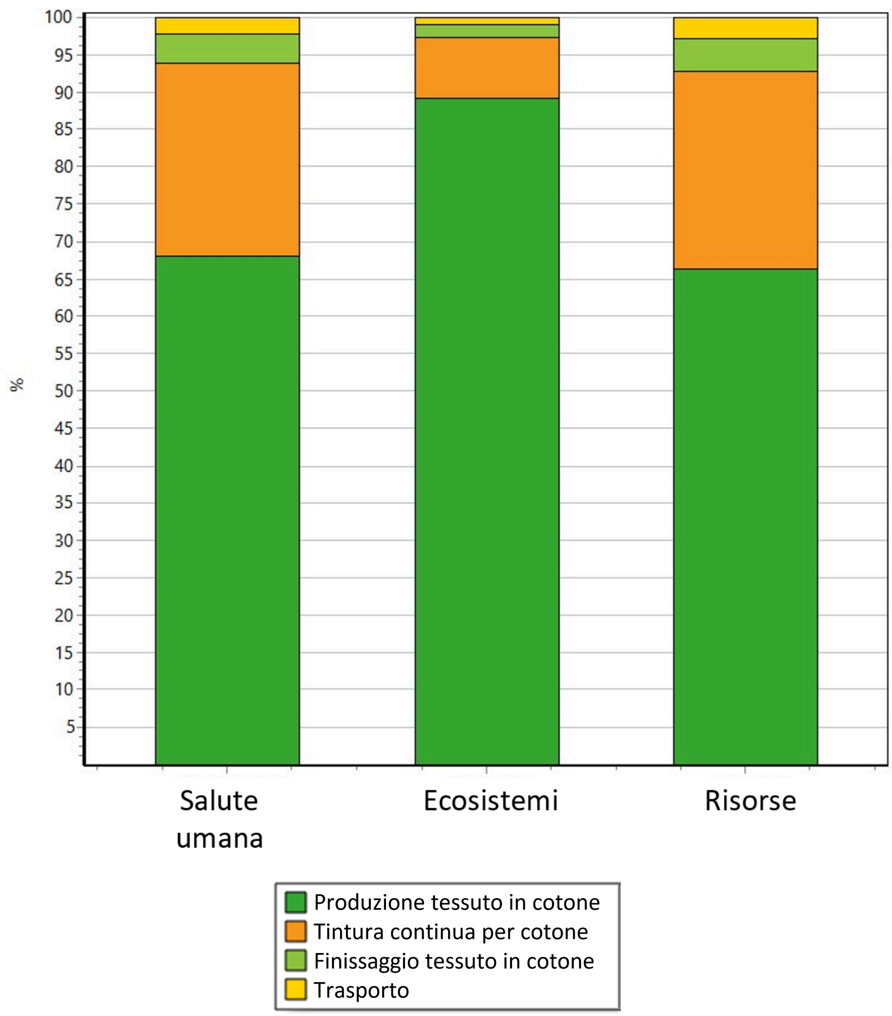

Figure 7.2 - Percentage incidence of impacts related to different production phases of the reference product (Denim Standard), divided by endpoint.

Considering instead the absolute impacts for each of the three endpoints, it is evident that the greatest impacts (0.675 Pt out of 0.729 total) occur in terms of human health (Figure 7.3) and represent over 90% of the overall impact, downstream of the weighting phase. 7% of the impacts (0.048 Pt) concern ecosystems and only 1% concerns the consumption of non-renewable resources (0.006 Pt). This disproportion in impacts across different endpoints is primarily related to the use of fossil fuels for electricity production used in various processes, which generates air emissions hazardous to human health, and secondarily to the chemicals used during cultivation, dyeing, and finishing. The impact on the decrease in the availability of fossil resources is less significant than that on health.

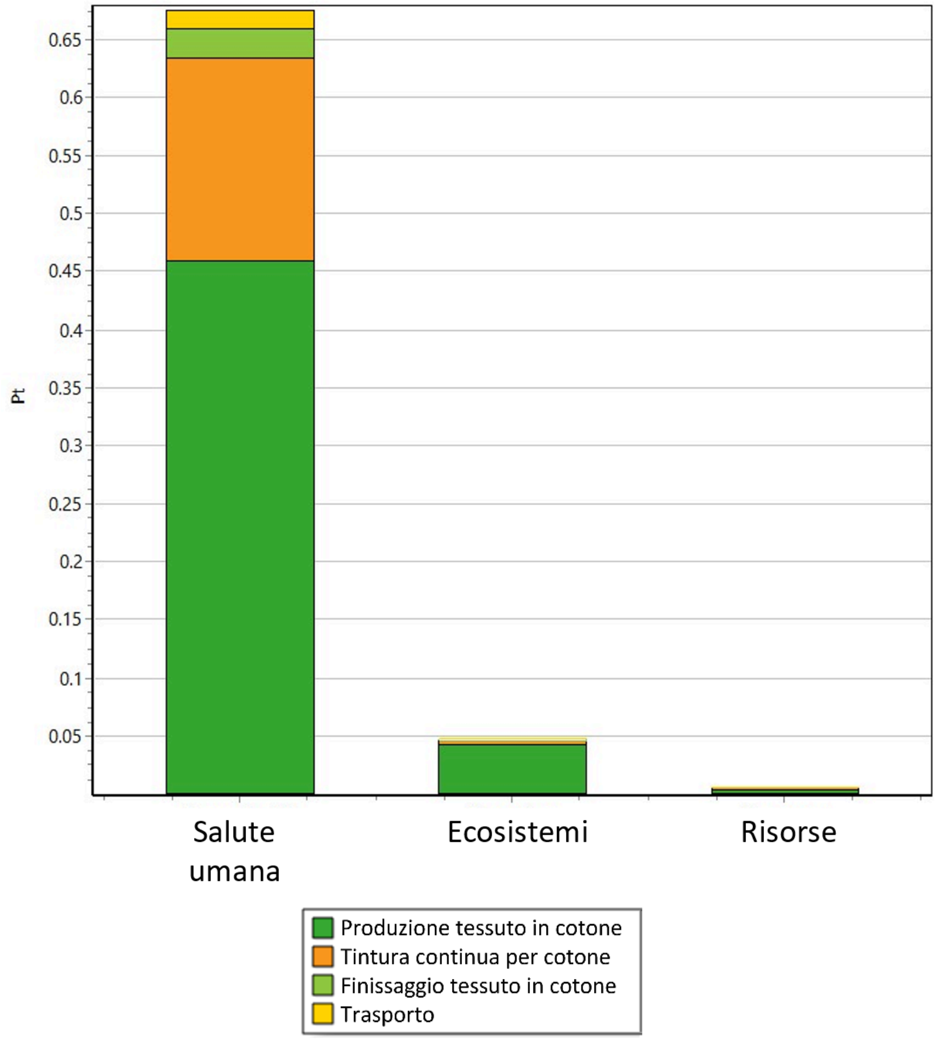

Figure 7.3 - Impacts (Pt) related to the different production phases of the reference product (Denim Standard), divided by endpoint

Analyzing the environmental impacts of the different production processes after the weighting phase, it is observed that all contribute to impacts on human health, while only the production of fabric has noticeable impacts on ecosystems (Figure 7.4).

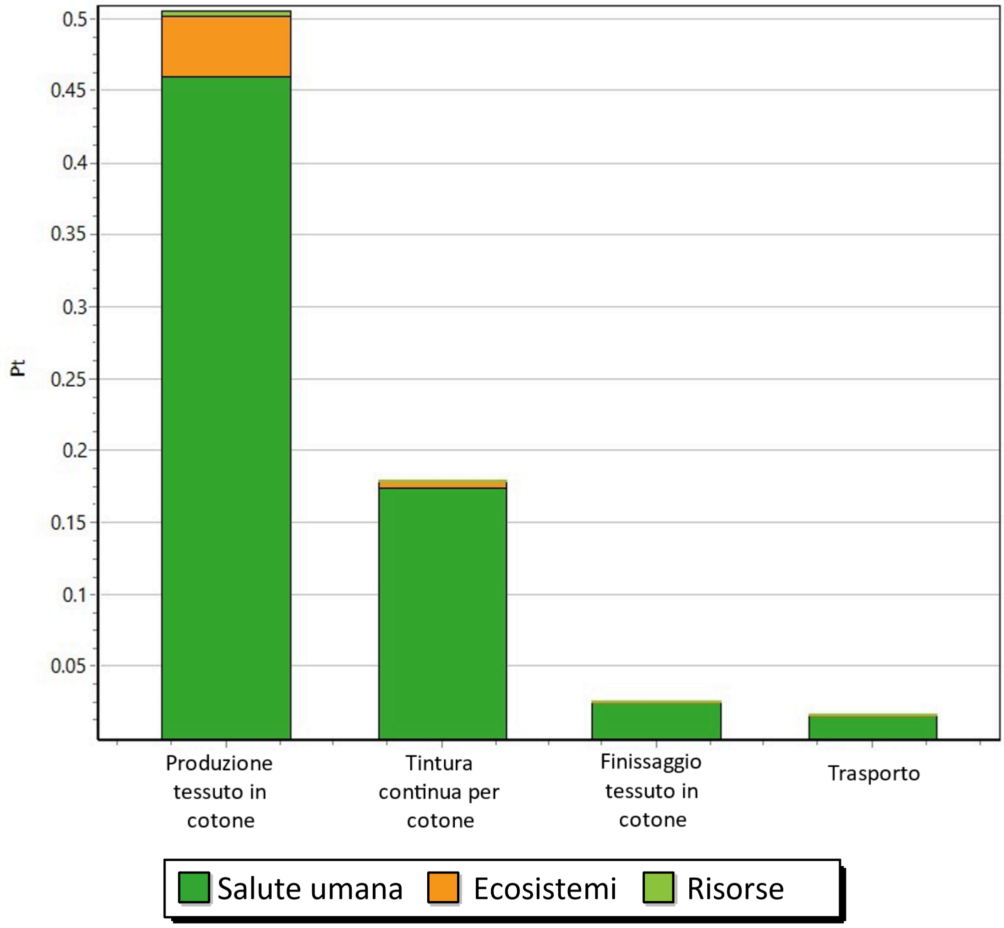

Figure 7.4 - Impacts related to the production of the reference product (Standard Denim) on the three endpoints, divided by production process.

Table 7.1 shows the relative impacts of the main processes, materials, and resources required to produce 1 kg of standard denim fabric. For the impact assessment, 5,664 processes were considered (Appendix 1); the 13 processes listed in the table account for more than 50% of the total impacts, with cotton fiber production, dyeing, and energy use (electricity, heating, and transportation) being the main sources of impact. Despite their overall significance, processes contributing less than 1.20% are not listed for space reasons.

Table 7.1 - Relative impacts (%) of individual processes related to the production of Standard Denim that produce the highest specific impact. The geographic relevance for each process considered is indicated in parentheses.

Process	**Total**	**Production of cotton fabric**	**Continuous dyeing of cotton fabric**	**Cotton fabric finishing**	**Transport**
Total	*100*	*100*	*100*	*100*	*100*
Processi rimanenti	49,82	52,19	46,32	60,33	0,00
Produzione convenzionale di semi di cotone (India, Gujarat)	11,40	16,42	0,00	0,00	0,00
Produzione convenzionale di semi di cotone (Resto del mondo)	8,43	12,15	0,00	0,00	0,00
Tintura continua per fibre di cotone (Globale)	8,07	0,00	32,70	0,00	0,00
Calore, distrettuale o industriale, diverso dal gas naturale 1-10MW (Resto del mondo)	4,78	0,83	13,12	26,90	0,00
Irrigazione superficiale (India)	3,16	4,55	0,00	0,00	0,00
Aratura (Resto del mondo)	3,07	4,42	0,00	0,00	0,00
Elettricità ad alta tensione (Indonesia)	2,41	2,31	2,67	4,01	0,00
Trasporto merci via nave (Globale)	2,32	0,00	0,00	0,00	100,00
Elettricità ad alta tensione per uso interno nell'estrazione del carbone (Cina)	1,60	1,33	2,20	3,85	0,00
Elettricità ad alta tensione (India, Chhattisgarh)	1,26	1,61	0,45	0,68	0,00
Elettricità ad alta tensione (India, Maharashtra)	1,24	1,60	0,45	0,67	0,00
Elettricità ad alta tensione (India, Uttar Pradesh)	1,23	1,58	0,44	0,67	0,00
Carbone fossile (Cina)	1,20	1,00	1,65	2,89	0,00

7.2 Post-Consumer Recycled Denim

The most significant impact categories are those related to global warming (47%), the formation of fine particulate matter in the atmosphere (27%), and the emission of substances with carcinogenic and non-carcinogenic effects on human health (Figure 7.5). A particularly relevant source of impact is the land use associated with the fabric production phase, especially the production of organic cotton. Although primary data for this phase of the process are not available, it is reasonable to assume that a more environmentally conscious production (organic, biological, regenerative, etc.) results in lower specific yields, translating into both increased land use and decreased chemical consumption compared to standard cultivation.

The overall impact balance on water consumption is negative (more water is emitted than consumed) because the reduced consumption associated with recycling part of the cotton significantly offsets that required for the cultivation of RG cotton and subsequent processing phases.

For all impact categories considered, fabric production is the most significant process, except for non-carcinogenic effects on human health. In this case, the impact balance up to the weaving phase is negative due to reduced emissions (-124%) associated with the recycling of part of the cotton and reduced chemical use for RG cotton cultivation, while dyeing (155%) and finishing (62%) phases are the most impactful.

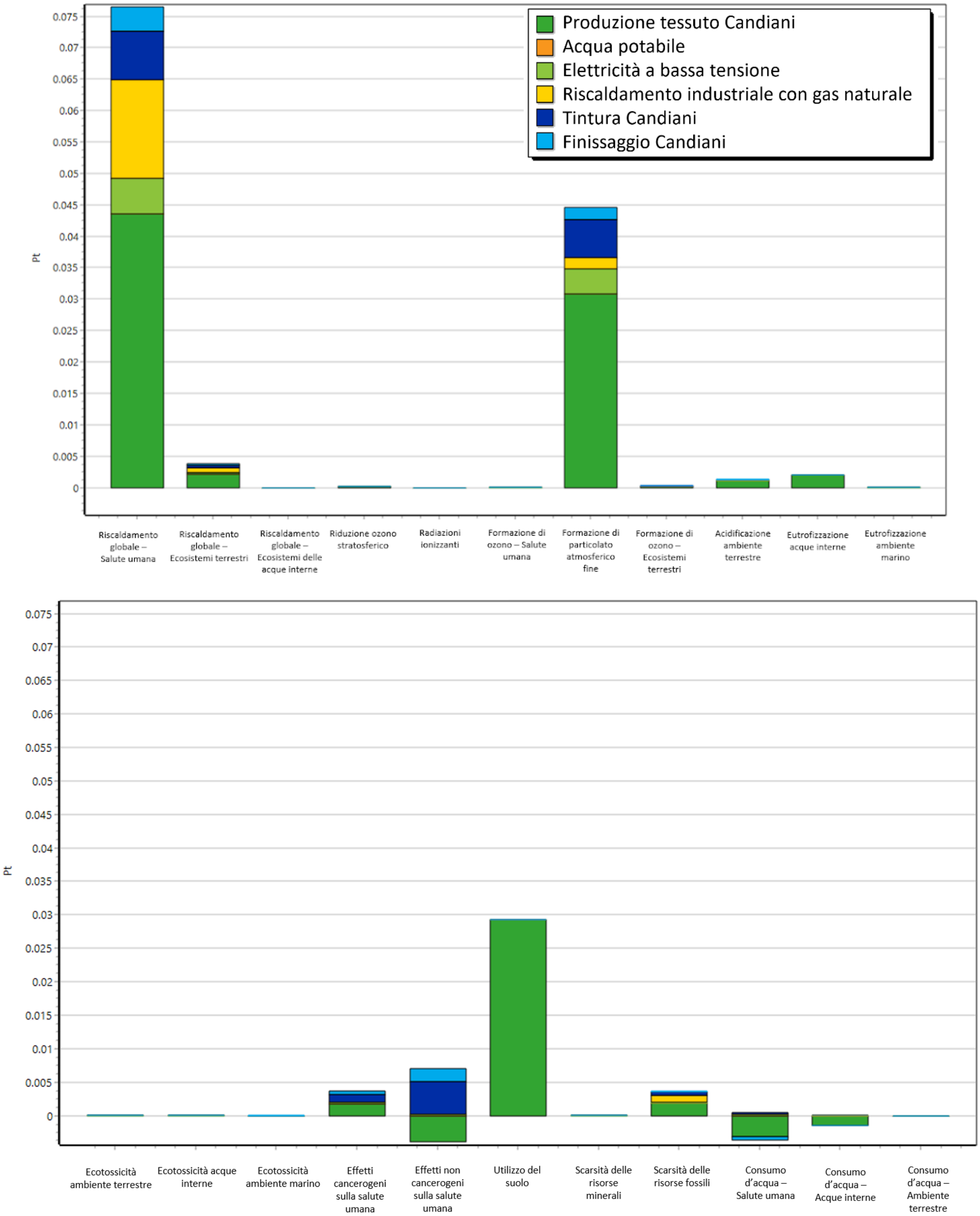

Figure 7.5 - Impacts of the production of the studied product (Denim Post Consumer Recycled) in Pt, divided by impact categories

Considering the relative impacts of different processes for each of the three considered endpoints, fabric production is the process that causes the greatest environmental impacts, ranging from 50% to more than 90% (Figure 7.6). The impacts related to electricity, heating, and potable water consumption shown in Figures 7.5, 7.6, 7.7, and 7.8

refer to those consumptions not attributable to specific processes but rather to operations at the Candiani facility.

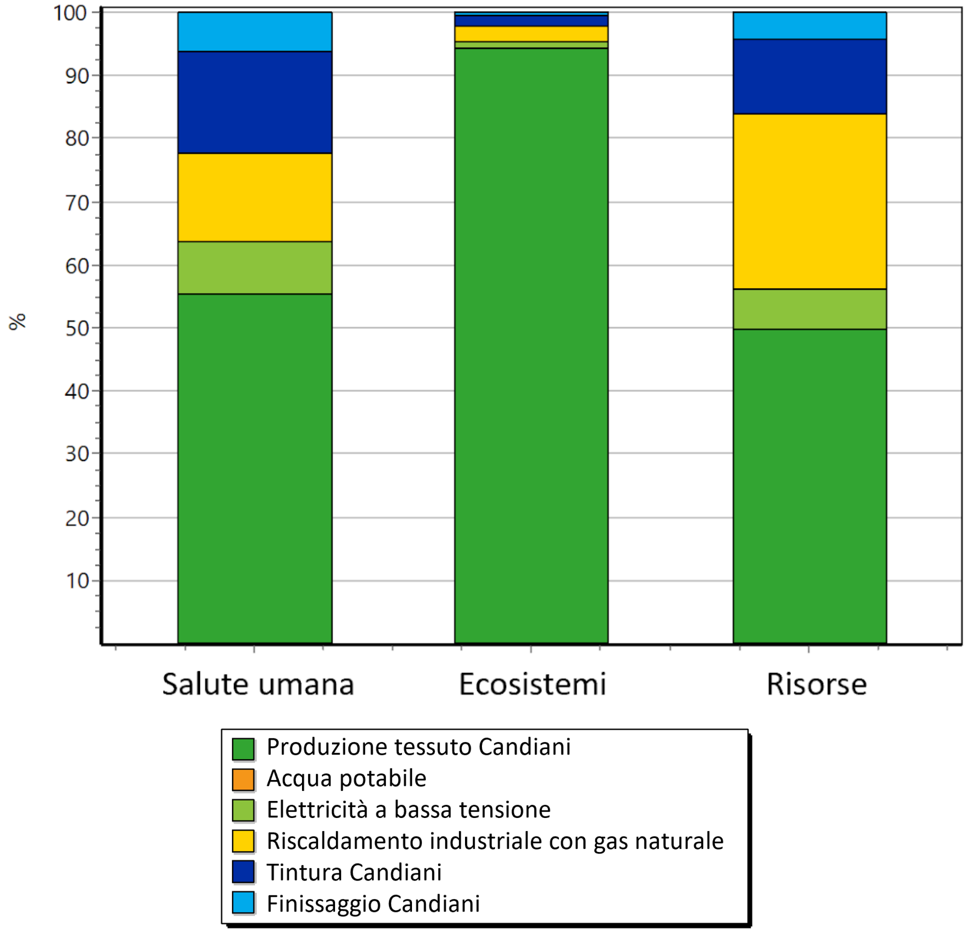

Figure 7.6 - Percentage incidence of the impacts related to the different production phases of the studied product (Denim Post Consumer Recycled), divided by endpoint.

Considering the impacts in Pt for each of the three endpoints considered, it is evident that the endpoint most affected is again human health (Figure 7.7), which accounts for over 75% of the total impacts (0.125 Pt out of a total of 0.164 Pt) after the weighing phase. This is followed by impacts on ecosystems (22%, 0.035 Pt) and the consumption of non-renewable resources (2%, 0.004 Pt). The impacts of the dyeing and finishing processes, as well as those related to energy consumption, are significant only for human health impacts, while they have a minor contribution to the other endpoints.

The observed disproportion between the impacts on the different endpoints is also related in this case to the use of fossil fuels for the production of electricity used in the various processes and to the relatively contained impacts on ecosystems from the chemicals used during the dyeing and finishing phases. Again, the availability of fossil resources is relatively less impacted since combustion, compared to other possible uses, is the one that, for equal consumption, causes the greatest impact on health.

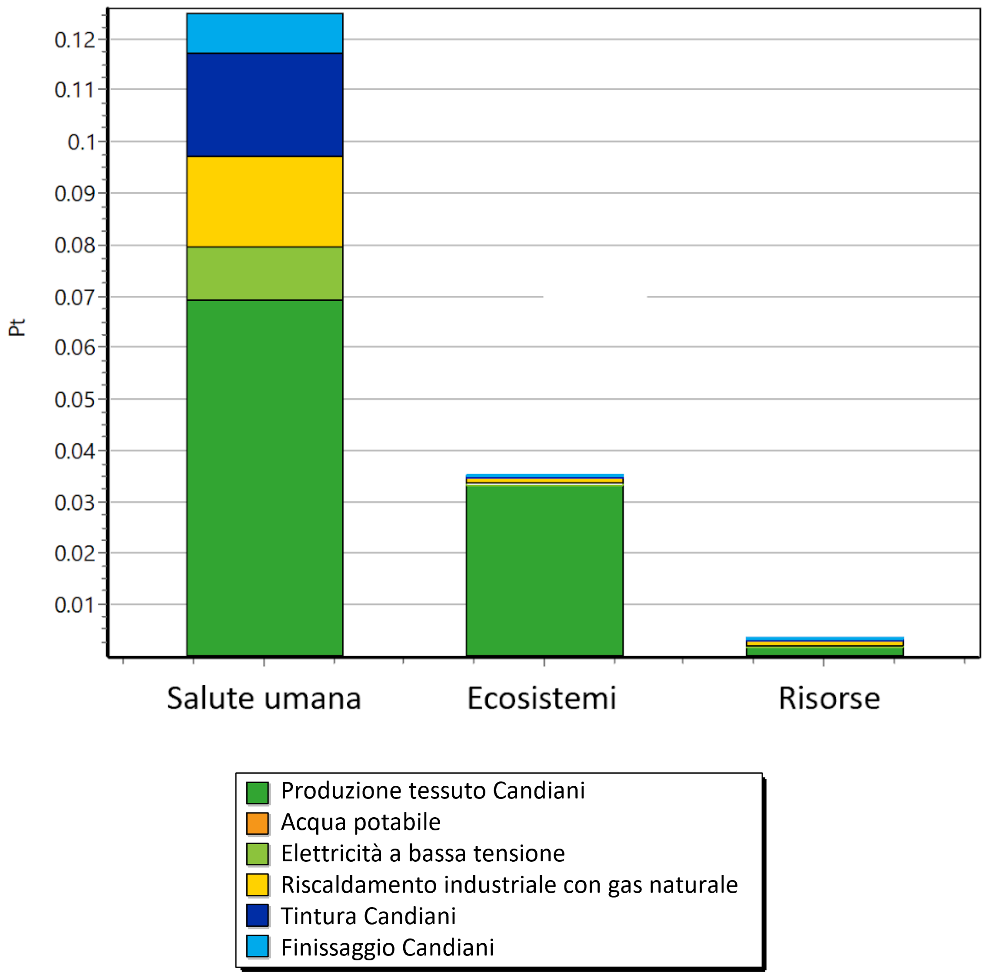

Figure 7.7 – Impacts (Pt) related to the various production stages of the studied product (Denim Post Consumer Recycled), divided by endpoint

Analyzing the environmental impacts of the various production processes after the weighing phase, it is observed that all processes predominantly contribute to impacts on human health, and only fabric production has significant impacts on ecosystems (Figure 7.8).

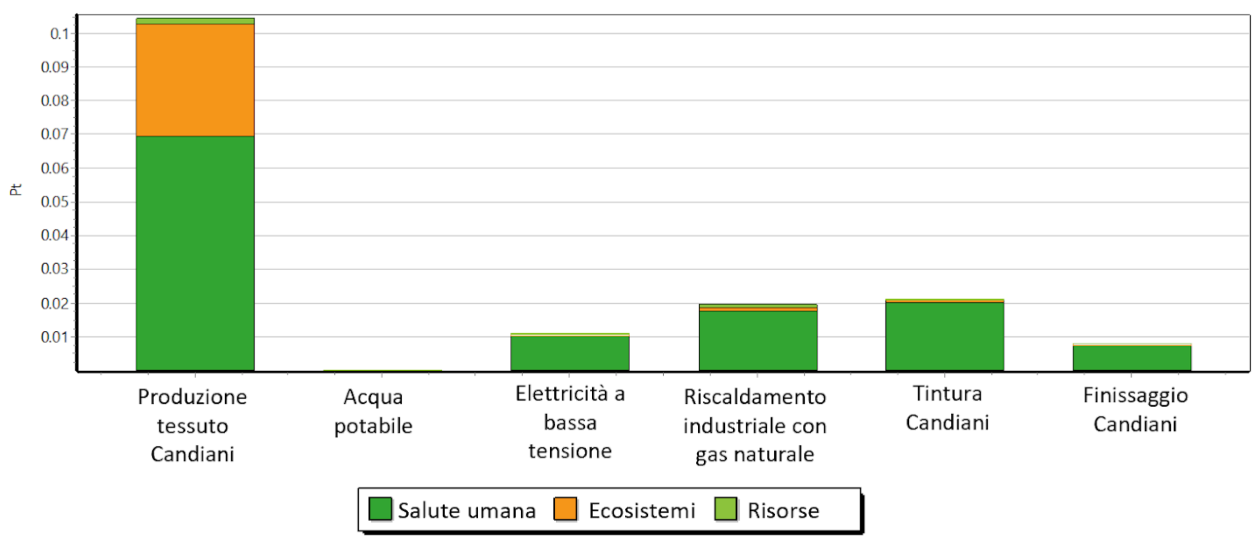

Figure 7.8 – Impacts related to the production of the studied product (Denim Post Consumer Recycled) on the three endpoints, divided by production process

Table 7.2 shows the relative impacts of the main processes, materials, and resources required for the production of 1 kg of "Candiani Denim Post Consumer Recycled". For the impact assessment, 5,688 processes were considered (Appendix 2); the 13 listed in the table account for more than 90% of the total impacts. In particular, the production of organic cotton fibers and the use of energy (electricity, heating, and transportation) represent the main sources of impact, while the avoided production of fibers and fabrics due to recycling significantly contributes to reducing the overall impacts of the studied product.

Table 7.2 - Relative impacts (%) of individual processes that produce the highest specific impact. Processes with contributions below 0.50% are not shown. The geographical relevance of each process considered is indicated in parentheses.

Process	**Total**	**Production Candiani fabric**	**Deying Candiani**	**Finishing Candiani**	**Elettricità a bassa tensione**	**Riscaldamento industriale con gas naturale**	**Drinking Water**
Il totale di tutti i processi	*100*	*100*	*100*	*100*	*100*	*100*	*100*
Processi rimanenti	7,41	-0,19	15,15	0,70	0,00	46,81	100,00
Elettricità in bassa tensione (Italia)	72,88	96,73	13,32	59,22	100,00	0,00	0,00
Produzione organica di semi d cotone (Globale)	42,20	66,26	0,00	0,00	0,00	0,00	0,00
Riscaldamento industriale con gas naturale (Europa esclusa la Svizzera)	6,32	0,00	0,20	0,00	0,00	53,19	0,00
Trasporto merci con camion Euro6 16-32 tonnellate (Europa)	5,39	8,46	0,00	0,00	0,00	0,00	0,00
Idrossido di sodio, senz'acqua, come soluzione al 50% (Globale)	4,05	0,00	31,30	0,00	0,00	0,00	0,00
Processo di tintura presso Candiani (escluse le materia prime)	3,43	0,00	26,49	0,00	0,00	0,00	0,00
Riscaldamento industriale con gas naturale (Europa)	2,41	0,11	13,54	12,01	0,00	0,00	0,00
Rifiuti organici (Resto del mondo)	1,51	2,37	0,00	0,00	0,00	0,00	0,00
Processo di finissaggio presso Candiani (escluse le materia prime)	1,37	0,00	0,00	28,07	0,00	0,00	0,00
Elettricità in bassa tensione (Spagna)	1,22	1,91	0,00	0,00	0,00	0,00	0,00
Scarti di filati e tessuti (Globale)	0,66	1,04	0,00	0,00	0,00	0,00	0,00
Tessuto non-tessuto in poliestere (Globale)	-3,26	-5,13	0,00	0,00	0,00	0,00	0,00
Tessuto in cotone (Globale)	-45,59	-71,58	0,00	0,00	0,00	0,00	0,00

7.3 Comparison of Impacts

The impact categories in which significant reductions are observed in the production of Post Consumer Recycled Denim compared to Standard Denim are the release of substances with non-carcinogenic effects on human health (-96%), the formation of fine particulate matter (-86%), and global warming (-66%). The comparison of water consumption impacts between the two products is particularly favorable to Post Consumer Recycled Denim, as shown in Figure 7.10. The only impact category for which Post Consumer Recycled Denim has greater environmental impacts than Standard Denim is land use, which is negatively affected by the lower productivity of organic cotton compared to conventionally grown cotton.

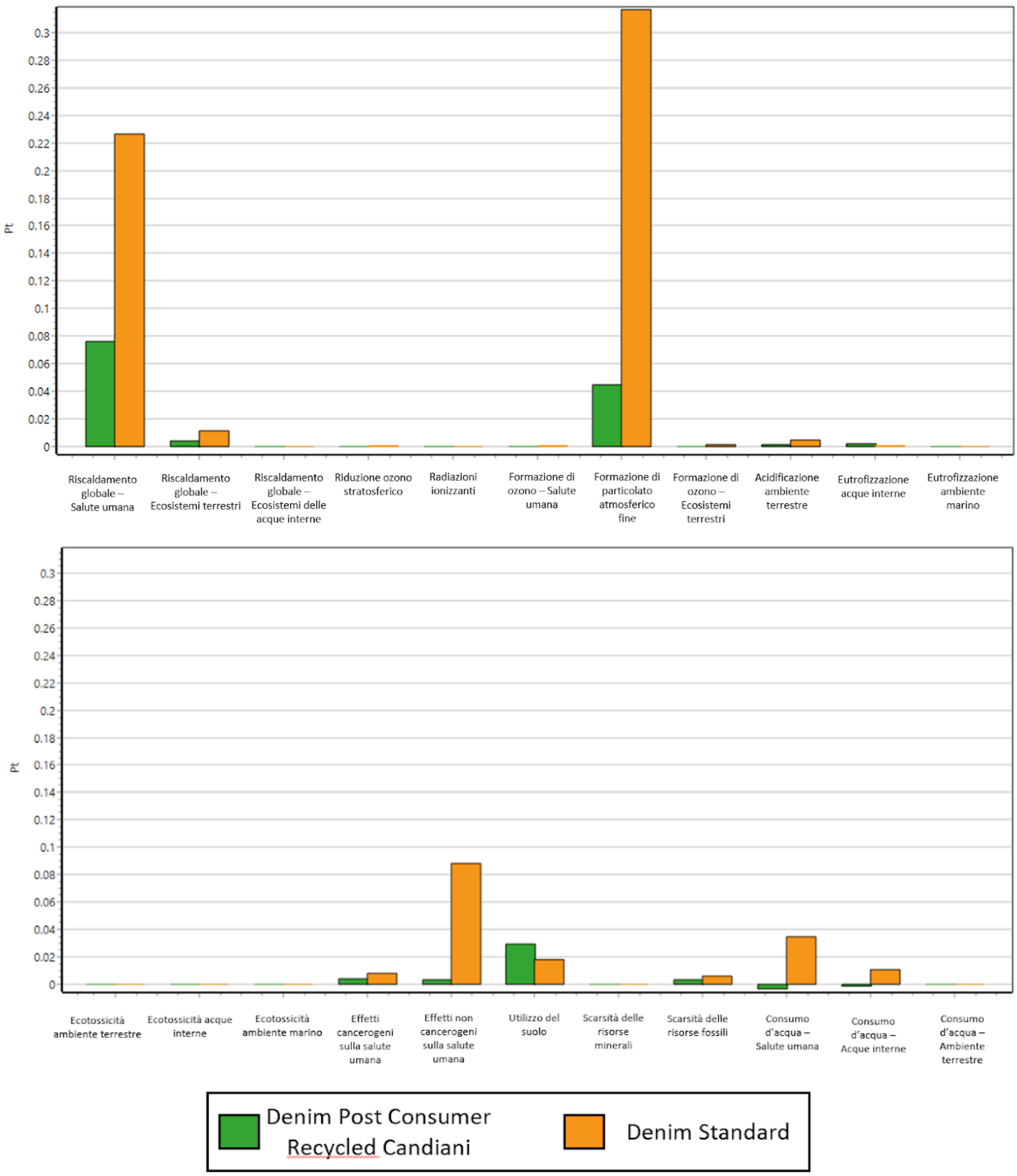

Figure 7.10 - Comparison of the impacts, in Pt, of the two products across different impact categories

The overall impact of Post Consumer Recycled Denim is 0.565 points lower than that of Standard Denim considered in this study. The magnitude of the difference is significant, given that it represents 78% of the total impacts of Standard Denim.

Comparisons for the sum of all impact categories are shown in Figure 7.11.

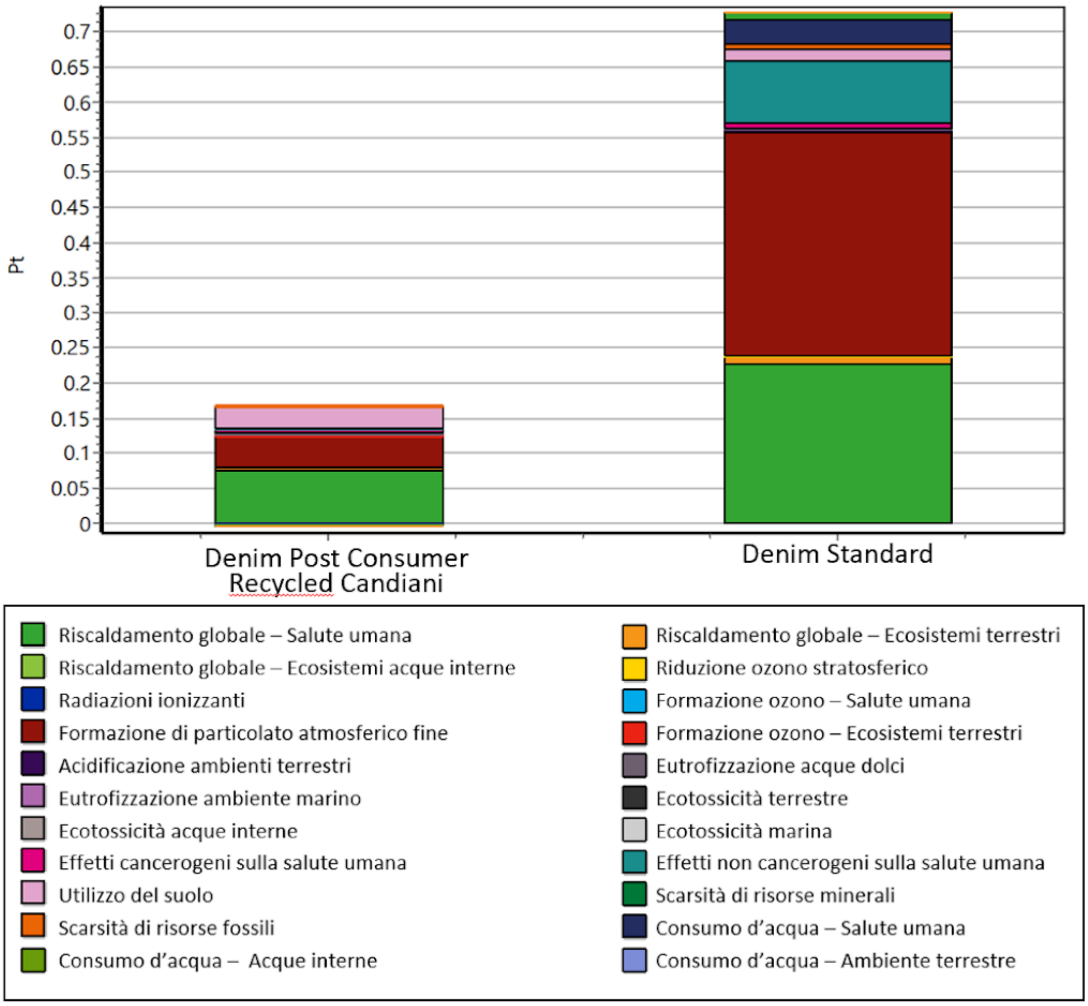

Figure 7.11 - Comparison of the absolute impacts, in Pt, of the two products across impact categories

Comparing the impacts in Pt for the sum of the three endpoints, Figure 7.12 clearly shows that the reduction in impacts is particularly significant for human health.

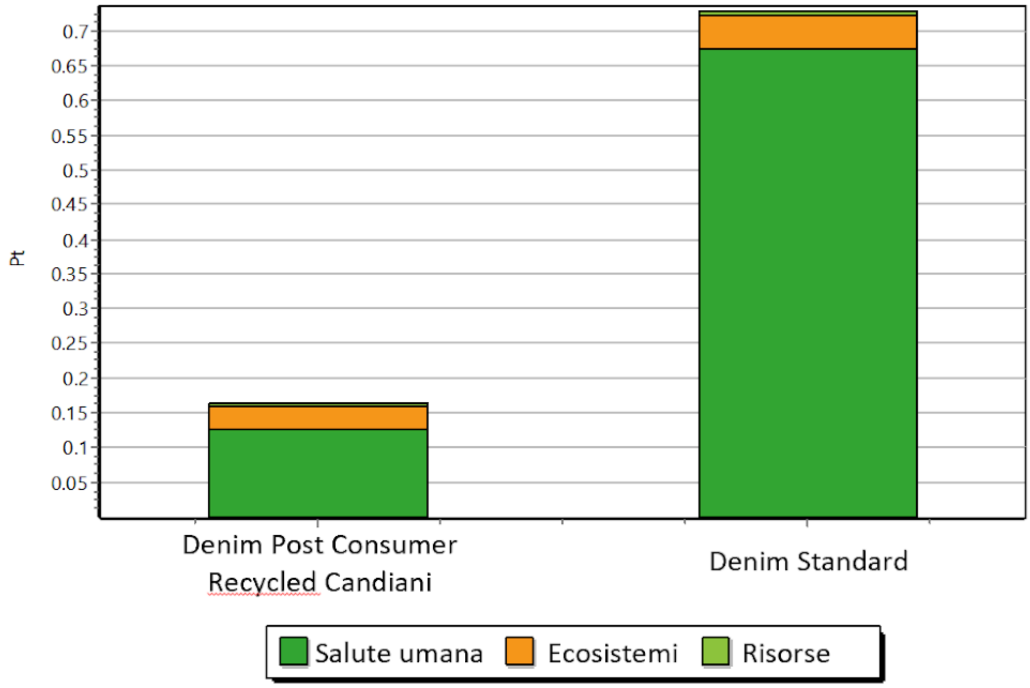

Figure 7.12 - Comparison of the absolute impacts, in Pt, of the two products on the three endpoints

Considering the impacts relative to each of the three endpoints considered, it is observed that the environmental performance of Post-Consumer Recycled Denim is always better than that of Standard Denim. In particular, the impacts on human health of Post-Consumer Recycled Denim are about 20% of those of Standard Denim, the impacts on ecosystems are 75%, and those on non-renewable resources are 60% (Figure 7.13).

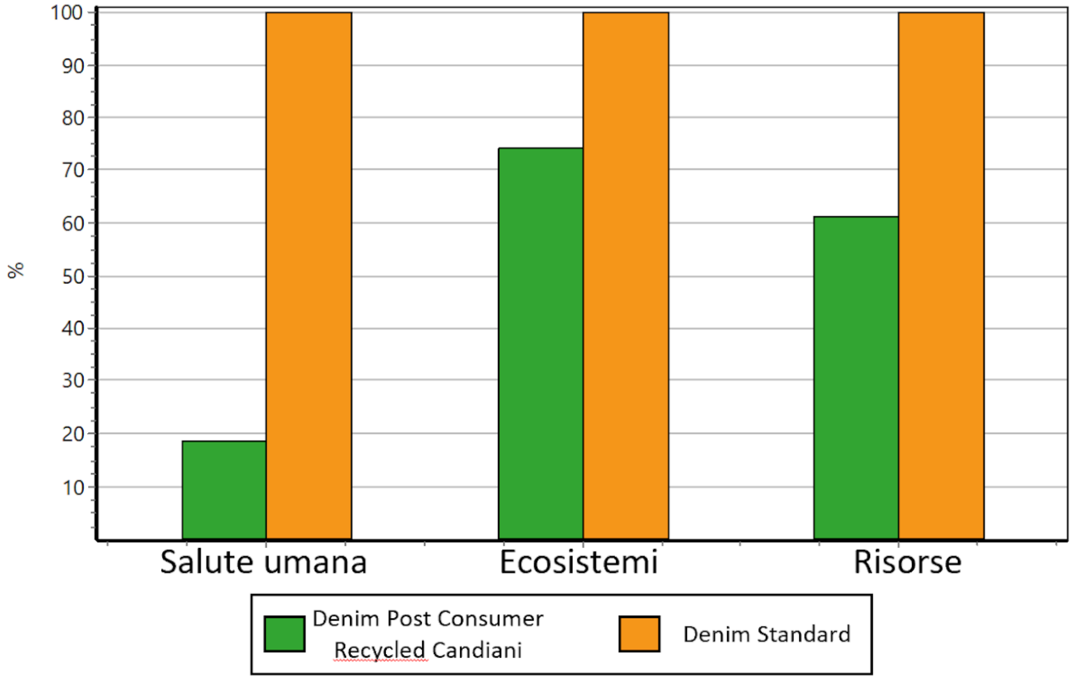

Figure 7.13 – Comparison of relative impacts, divided by endpoint. The impact of Standard Denim is set at 100%, and that of Post-Consumer Recycled Denim is reported as a relative percentage.

Considering the absolute impacts for each of the three endpoints considered, it is evident that the endpoint where the impact of Post-Consumer Recycled Denim is significantly lower, namely human health, is also the one most affected by the process in both cases. (Figure 7.14).

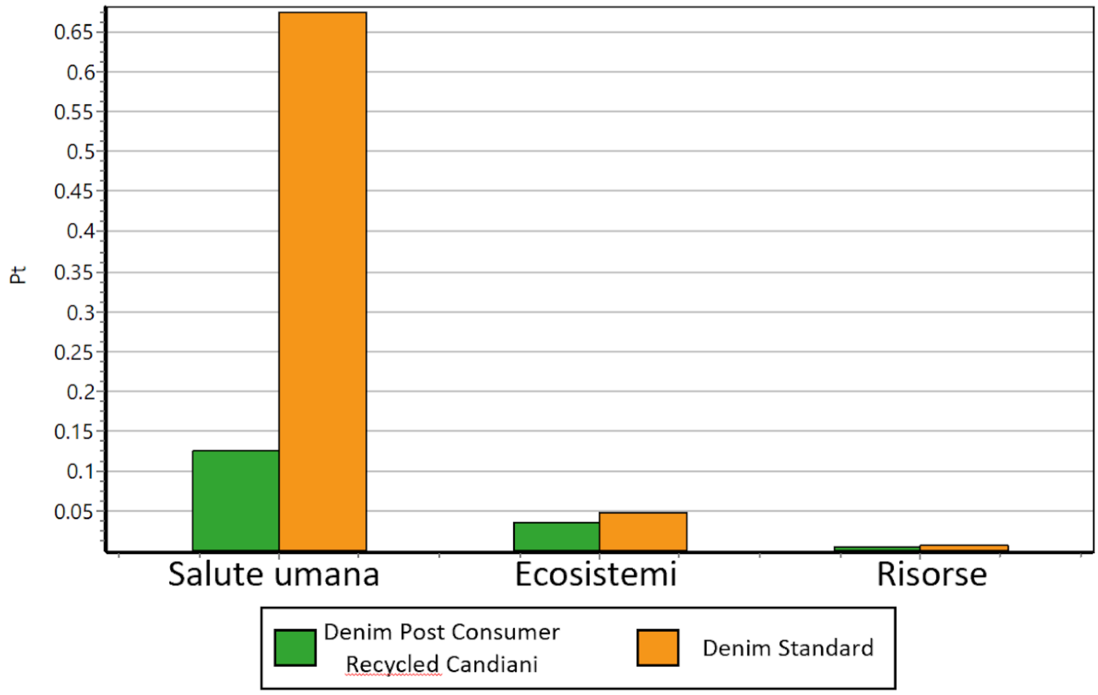

Figure 7.14 - Comparison of the absolute impacts of the two products (in Pt) on the three endpoints.

It is not surprising, therefore, that this is also the area where most of the differences are found (Figures 7.13 and 7.14). On the contrary, the absolute impacts on ecosystems and non-renewable resources do not show substantial differences between the two products (Figure 7.14). An effect of the reduction in absolute impacts on human health is the increased relative importance of impacts on ecosystems and resources for Post-Consumer Recycled Denim compared to Standard Denim (22% vs. 7% and 2.2% vs. 0.8%).

8 Conclusion

From a qualitative perspective, the analyses conducted highlighted similar environmental footprints between Standard Denim and Post-Consumer Recycled Denim, with impacts primarily affecting human health and, to a lesser extent, ecosystems and non-renewable resources. Quantitatively, the comparison between the two products revealed that the processes used for producing Post-Consumer Recycled Denim result in a significant reduction in impacts on global warming, the release of substances with non-carcinogenic effects on human health, the formation of fine particulate matter, and water consumption. The better environmental performance of Post-Consumer Recycled Denim is largely due to the use of PCR denim, which significantly reduces the amount of virgin cotton required (24%) and promotes the recycling and reuse of materials that would otherwise be produced from scratch, resulting in greater environmental impacts. The use of organic cotton instead of standard cotton also contributes to reduced environmental emissions, though it simultaneously increases impacts on land use, particularly concerning the area needed for cultivation. Water savings are primarily due to the absence of cotton production thanks to recycling, but an important contribution also comes from the return of partially treated water after the finishing process.

Regarding the potential for further reducing environmental impacts, the high energy usage for heating should be noted. If not already done, it would be advisable to evaluate additional strategies for heat recovery from machinery or improving the energy efficiency of buildings. Current electricity consumption causes a significant portion of the impacts on human health. Regardless of the energy mix used (Italy or other countries), a substantial part of the energy comes from the combustion of fossil fuels. The use of complementary energy sources (e.g., photovoltaic, geothermal, hydroelectric) to the “standard” market-provided energy represents a valid tool for reducing the overall impacts of the studied product.

The process of cultivating long-fiber regenerative cotton would require a specific evaluation that could highlight the most critical phases from an environmental perspective. Other processes analyzed already show better performance in the case of Post Consumer Recycled Denim compared to Standard Denim, so the margin for improvement is fairly limited.

The main limitations of this study are related to the cotton cultivation phase, for which primary data are not available. The alternative product used in the analysis phase (globally produced organic cotton) represents a conservative choice compared to the long-fiber regenerative cotton produced by Algosur S.A., as the Spanish situation should ensure better environmental standards than the global average. For all other processes, it was possible to evaluate the actual energy and resource consumption, while emissions in various compartments related to machinery use were estimated based on emission coefficients of processes with similar technologies available in the Ecoinvent database. Another aspect that could be explored further is the allocation of impacts of the processes managed by Humana People to People Italia, particularly regarding the types and quantities of products actually avoided.