Master Thesis

LCA of THE RÚA INTIMATES (Underwear Start-up)

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Abstract: The fashion industry has suffered an unstoppable growth in the last decades. This growth isn't aligned with sustainability goals, but there are means to change this tendency. Underwear, as part of the fashion industry, also needs to change the linear unsustainable path followers until the moment. LCA is able to provide data about the processes that have the most important impacts in the life of a product, in order to make improvements. This study uses Life Cycle Assessment to analyze a particular brand that started its business un 2021 with the purpose of being sustainable to explore which parts of the value chain have the greatest environmental impacts. The results show that the materials used have less impact than the direct organic substitutes and that the stages that are causing the biggest impact in the whole life cycle are the fabrication process of the main textiles used and the use cycle.

Keywords: LCA, Textil, Lingerie, recycled PET

1. Introduction

It is hard to imagine the life without clothing since it has been present since it has been present for 100000 to 500000 years ago in the Neanderthal era, for modesty and protection [1]. Nowadays, fashion industry understood as the sector in charge of creation, production, distribution, and consumption of fashion, is the seventh largest economy. Its global revenue was estimated to be between 1.7 and 2.5 trillion dollars in the year 2019. Even though, the year of the pandemic the incomes were lower, fashion industry figures returned to pre-pandemic figures in what was known as revenge shopping. The forecast for this year 2022 is that the market reaches a growth of 6.1 % [2]. These tendencies of unlimited growth in addition to the linear operating system of this industry has serious environmental impacts. The lack of circularity in this sector means the extraction of large amounts of non-renewable resources, a short period of usage, non-recycling, and the releasing of hazardous substances. The goal now is transforming this industry, but it requires a system-level change with a high degree of commitment, collaboration, and integration.

Even though there is a big challenge ahead this sector, there is an increasing number of brands appearing and modifying its production chain, in order to get results and disrupt the current system to create sustainable goods [3].

Life Cycle Assessment was conceived in the 1960s when the environmental degradation became a concern, but it wasn't until the 1990s, when the universities started developing a methodology when it started to make an impact, and its goal was to account the flows in the life of an object to assess the environmental impacts potentials in order to avoid them [4]. For the reasons mentioned above, fashion industry has become in the last decades as a continual consumption loop, where the "old" is discarded and the "new" becomes prematurely obsolete. This unnecessary consumption runs against the principles of sustainability and today tendency of anti-consumption messages is forcing the companies in general, and the fashion firms in particular to reduce their environmental burdens [5], this is where LCA in necessary, to enlighten the processes and stages that can be avoided.

One of the many branches of the fashion industry is the intimate clothing one, which is also experiencing changes in aims to become more sustainable. The RÚA Intimates is a self-owned brand that started in the year 2021 with the aim of offering intimate clothing able to provide comfort and self-security products that are also aligned with sustainable goals. This is a doble challenge, not only it is one branch of fashion where sustainability tends to be overlooked, but it is also a small brand with high dependency on its providers. Considering this, the objectives are the following:

- Research about fashion industry, more precisely about the underwear branch and its environmental impacts.

- Research on LCA textiles and potential environmental impacts of them.
- Study the impacts of the brand RÚA INTIMATES to be able to provide concise information for the costumers about the products.
- Bring awareness of the impacts of the use of the products to the costumers.
- Provide possible improvements for the brand.

The brand, RÚA INTIMATES, offers 2 different sets of briefs and bras, in two different colors, white and black, and a body. The brand is self-owned and managed by the CEO [6]. She is in charge of the design of the clothes of the brand, buys the required material to third parties and subcontracts the production to a sewing workshop. The products are available in the webpage of the brand [6]. This means the brand only has one employee, and the total production has been since year 2021, when the brand started, 30 pieces of each one of the sets Amaro and Aldán, Figure 1 (a), (b), (c) and (d) and 40 pieces of the body Udra Figure 1 (e).


(a)


(b)


(c)


(d)

(e)

Figure 1. Lingerie products of RÚA INTIMATES sold until june 2022. (a) and (b) Aldán Sets in colours white and black, (c) and (d) Amaro sets in colours white and black and (e) body Udra **[6]**.

The dimension of the brand makes it difficult to control all the steps that take place in the textile production and distribution chain. To ensure as much as possible the sustainability along the supply chain the main strategies are the following:

- The main textiles for the clothing items must be certified. In this case, they have OEKO-TEX Standard 100 certification that make them hygienic and suitable for their use in lingerie and the fabric made in Italy certificate. Also, in the case of Saten Ecostrech fabric, it includes the REACH certificate that verifies that suppliers operate with safety standards for chemicals and raw materials and the GRS certificate that verifies that the materials are recycled. To obtain the last certificate, the requirements are that at least 20% of the materials used are recycled. In this case, it was proven that 100% of the materials listed as recycled where actually recycled.
- The rest of the materials are provided from Spanish retailers in local stores (Ribes & Casals and El Almacén de Pontejos), except in the case of the ribbons which are purchased from a Japanese company (Mokuba Ribbons).
- Make the whole production in Spain, in a local sewing workshop, where the workers have decent working and living conditions.

There are many environmental burdens derived from the synthesis process of textiles [7].

- **Raw materials**. In this case, the raw materials used for the main fabrics are in the case of Plumetti Caprice polyester with elastane and in the case of Saten Ecostrech recycled polyester and elastane. Polyester and elastane have similar energy inputs and come from oil. Recycled polyester normally has a lesser grade quality grade than virgin polyester, but it requires 70% less energy than virgin polyester, it keeps bottles out of landfills and saves petroleum and dependency on oil [8].
- **Energy consumption**. Apart from the high amount of energy required from the production process, all the transport, the energy in the sewing facility, in the multiple washing cycles. This energy can be consumed as diesel or gasoline for transport, as natural gas in the factory or electricity in the sewing workshop, in the different processes or in the use cycle.
- **Water consumption**. Water consumption on the fibers production process is very low compared to organic fibers. However, the production of textiles does need a lot of water, for example when dyeing fabrics. It also needs a high quantity when it used for washing the clothes. The consumption of water translates in wastewater. In the case of the factory of the main fabrics, most of the wastewater is recirculated.
- **Waste**. Most of the waste produced are textile scraps in the sewing facility and in the factory.

Since all the estimations are based on the mass, the key parameter in this case is the grammage and density of the materials used.

4. Materials and Methods (Methodology)

The Life Cycle Assessment has the goal of providing an objective, systematic and methodical analysis of a product in this case, even though it can be applied to a process or service also. It is based on the international standards ISO 14040/14044 [9]. These standards are articulated in 4 stages shown in the Figure 2. The software used for the simulation and analysis of all the processes was SimaPro, the leading LCA software for over 30 years, designed to be a source of science-based information and avoiding black-box processes [10]. This tool is commonly used due to its access to Ecoinvent Database. Ecoinvent Database is the most used database in Europe and themost complete one also. Its aim is to provide data for environmental assessments to policy makers, private enterprises, NGO, and the academic community [11].

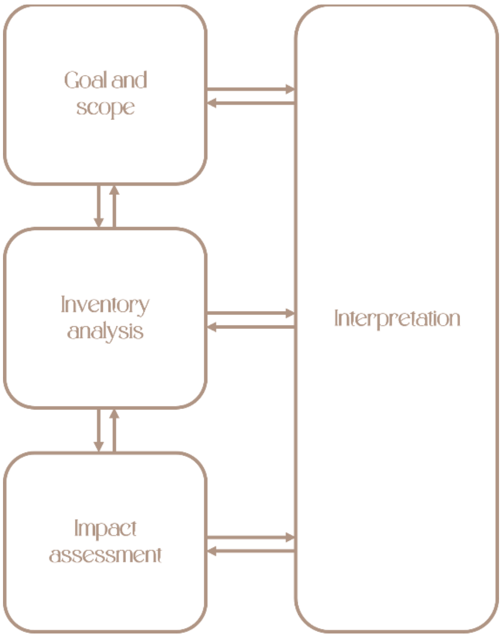


Figure 2. Life Cycle Assessment process based on ISO 14040/14044

4.1. Goal and Scope

The first step is to define the type of Life Cycle studied in this case. The type depends on the object studied, it can be oriented to analyze a product or a material. It will consider the production of the material, either if it is virgin or secondary, the manufacturing processes, its use and the waste management.

Life Cycle Assessment can also be classified as attributional or consequential. In this case, the assessment made will be attributional since it doesn't take into account the avoided processes, but only the environmental burdens that correspond to the product.

Once the object is defined, the method has to be chosen. The criteria to choose a method is that it has to be easy to use, generate accurate results that decision makers can understand and find relevant in their decisions, and they have to be robust enough to resist misuse. A

The first step in a Life Cycle assessment is to define the type of LCA used for the analysis. In this case, it must be considered that the purpose of this analysis is to provide information to RÚA's costumers and at the same time, give some recommendations to reduce the impact of the brand.

In this case, recycled materials are going to be used. When this happens, the person in charge of the study has to clarify what type of method is using and what stages are being considered. In this case, it can be seen in Figure 3 the end and start with discontinuous line.

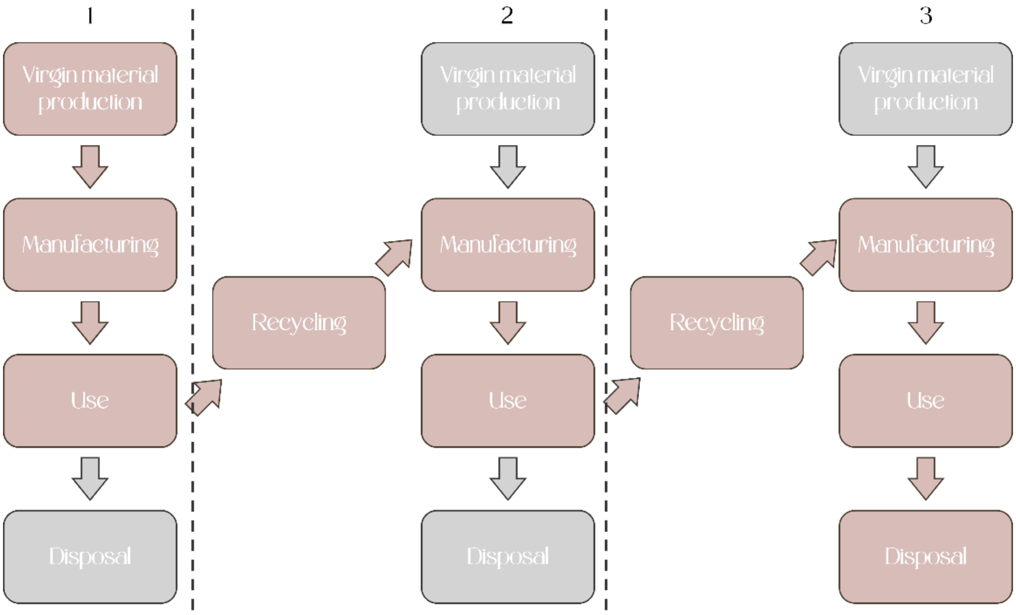


Figure 3. The blocks show the stages in the life of three products. The first of them requires the use of virgin material and the last means the disposal of all the products. The dashed lines show the stages that are taken into account in the analysis.

This method was chosen because it is unclear the amount of recycled output after its use, although it has been estimated, the brand is in control of the amount of recycled material being used. The formula for the given method is:

$$E = (1 - R_1) \times E_V + R_1 \times E_R + (1 - R_2) \times E_D \quad (1)$$

Where E is the total environmental burdens considered, R_1 is the rate of recycled material in the product, R2 is the rate of recycling material, E_R is the environmental burdens of the recycling activities and E_D is the disposal burden.

The scope of the analysis includes the raw materials to obtain the fibers, the transport of these fibers, the fabrication of the textiles from the fibers and their transport to the sewing facility, the energy used in the sewing facility, the last mile delivery, the washing of the clothing items and their final disposal. The functional unit is one piece of each product.

For the analysis the used method will be CML-IA baseline. This method was was designed to provide the baseline or standard categories that could be required in any life cycle assessment. They use indicators or units that can be easily translated into their potential harm and classified in different categories, shown in Table 1.

Table 1. Impact Categories of CML IA Baseline and their units.

Impact Category	Abreviation	Units
Abiotic depletion	ADep	kg Sb eq
Abiotic depletion (fossil fuels)	ADep FF	MJ
Global warming (GWP100y)	GWP100y	kg CO_2 eq
Ozone layer depletion (ODP)	OLDP	kg CFC^{-11} eq
Human toxicity	HumTx	kg 1,4-DB eq
Fresh water aquatic ecotox.	FWAEtx	kg 1,4-DB eq
Marine aquatic ecotoxicity	MAEtx	kg 1,4-DB eq
Terrestrial ecotoxicity	TeEtx	kg 1,4-DB eq
Photochemical oxidation	PhoChOx	kg C_2H_4 eq
Acidification	Acidi	kg SO_2 eq
Eutrophication	Eutro	kg PO_4 eq

4.2. Inventory Analysis

Once all the methods that are going to be used in this case are properly defined it's time to gather information about the products studied. This is the most sensitive part yet the hardest to obtain, since it depends on the providers and the information, they are able or willing to provide. There are cases where this type of information is easier to get. This is the example of the large corporates, that have control to the whole production chain. When the company is as small as it is in the case of study, the providers of most of the materials used are local distributors and have less scope of the origin of their products. This makes the tracking of data more challenging.

After listing all the materials and processes needed to model the life cycle of the clothing items, data was obtained following the directions below [12]:

1. List all the materials and processes needed to model the life cycle analysis of the clothing items.
2. Ask **the manufacturers** directly for data.
3. When data couldn't be provided by manufacturers, either because it wasn't available or there wasn't a direct connection with them it was obtained from processes available in the **Ecoinvent Database**.
4. When this data wasn't in the Ecoinvent Database, it was estimated combining information from articles and processes already available in the **Ecoinvent Database.**

Apart from explaining the materials used and the models and simplifications for each one of them, the first line provides a reason about why each piece is included in the design and why it can't be avoided.

4.2.1. Production Stage.

The input of materials is one of the key parts of the production. As it was discussed in the introduction, one of the key parameters is the weight of each clothing item, since it was the parameter used to assess the impacts. This means it will be decisive in the final numbers, therefore, each weight is provided in Table 2. Since they are usually sold together and meant to be worn together, the clothing items of the sets are studied together.

Table 2. Weights in grams of the Aldan, Amaro and Udra sets and each of their parts

Mass (g)	Aldan Set	Amaro Set	Udra Body
Saten Ecostrech	62.90	50.30	-
Plumetti Caprice	-	-	35.30
Viscose	19.34	19.34	19.34
Ribbon 4657	0,22	0.22	0.22
Ribbon 4668	-	0.34	-
Bra Adjuster	0.67	1.32	1.32
Ring	0.28	0.56	0.56
Total	**83.41**	**72.12**	**56.74**
Packaging		110,58	

One of the things that is going to be considered in the analysis is the transport the inputs to the sewing facility, since the origins where very different in each case as it is shown in Figure 4. The total km made by the raw materials that could be tracked down was estimated using Searates [13]. The distances travelled are provided in the Table 3 and Table 4.

Figure 4. Origin of the different parts of the sets in brown and from the raw materials used to make the main fabrics in pink. The arrows do not correspond with the route followed for the delivery.

Table 3. Material for the main fabrics, origins and travelled distance.

Fabric	Raw Materials	Origin	Density	Transport	Distance (km)
Saten Ecostrech	Recycled polyester Fibers	Turkey	Italy	Lorry	1923
	Elastane Fibers	UK	Italy	Lorry	1522
Plumetti Caprice	Polyester Fibers	China	Italy	Ship	17305
	Elastane Fibers	Korea	Italy	Ship	18135

Table 4. Materials for the sets and body, origins and travelled distance.

Parts of the set/body	Origin	Density	Transport	Distance (km)
Saten Ecostrech and Plumetti Caprice	Italy	Spain	Lorry	1613
Lining	Spain	Spain	Lorry	248
Ribbons	Japan	Spain	Ship+Lorry	19000+608
Ring/ Bra Adjuster	Spain	Spain	Lorry	700

Satin Ecostrech and Plumetti Caprice

The most significant part in terms of surface and weight are the main fabrics. The fabrics for the pieces of the brand are made in Italy and in this case the owner of the brand has direct contact with the provided.

The first information was the composition of each fabric. Satin Ecostrech's composition is 92% recycled polyester from Turkey and 8% elastane from United Kingdom, while Plumetti Caprice uses 79% of polyester (non-recycled) from China and 21% of elastane from Korea. As it can be seen there is already a big difference between both fabrics since one of them is mostly from recycled materials and the other isn't. Also, there is a big difference about the distance each of the raw materials have to make. This will suppose a high impact in the abiotic fuel emissions. The process of texturizing, warping, weaving, dyeing and finishing the fabrics was modeled with the inputs in the Table 5.

Table 5. Inputs provided by the fabric suppliers.

Input		Values	Units
Resources	Water	250	l/kg
	Disperse dye	<0.01	kg/kg
Energy	Electricity	5.1	kWh/kg
	Natural gas	2	m^3/kg
Waste	Fabric (waste)	0.053	Kg/kg

The production process for the raw materials was estimated using the ecoinvent database. Polyester fibers were available. They were included specifying the energy mix was chinese. The recycled polyester fibers weren't included, but recycled PET was. In this case, the process used for recycled polyester fibers was the non-recycled polyester fibers, replacing the raw material PET for r-PET, since the characteristics or both are the same and the only difference is their origin. For this case, the water and electricity inputs were specified as Italian.

Apart from PET and recycled PET, has been specified that there was also a lower content of elastane fibers, however, there wasn't information in the Ecoinvent Database. In another similar cases of clothing LCA, the fibers of elastane were modeled with the same process of polyester fibers, because energy inputs are similar in both cases [14], but using polyurethane foam as raw material, since 85% of elastane [15].

The use of certain substances should also be accounted to reproduce the process as truthful as possible. Dyes are used for the coloring of the fabric. The provider in this case couldn't specify the formula of the dye used, but they defined it as a disperse dye. Disperse dyes are used for coloring synthetic fabrics, such as the ones used for the clothing pieces, in the case of polyester the temperature is around 130ºC, considering 92% of the fabric is made of polyester, and this is the higher value of temperature used to dye fabrics, this is the temperature that is going to be considered. In this case both of the given sets are produced in black and white, and the body is only produced in black. Black disperse dyes are generally a mixture of pigments: a shade of navy, red and yellow or brown. The only ones included are the disperse yellow and blue, these were the only ones that could be found in the Ecoinvent library. In the case of the white pieces, the substance used is going to be brightening disperse dye [16].

Lining Fabric

The next fabric considered is the one used for the lining. This lining is placed in the interior of the briefs and body for hygienic purposes. In this case, the providers couldn't bring as much information as in the last one, since they act as intermediates with the brand. But the quantities used where known and they were able to provide the origin of the fabric (Burgos), the composition (95% viscose and 5% elastane) and the grammage of the fabric. Like in the previous case, there wasn't any information about the viscose textile. Once again, the literature recommended using the same energy demands as for polyester textiles with cotton fibers as an input [17]. Energy demands where considered with the Spanish electricity mix, as well as tap water was considered to come from Spain.

Ribbons

The ribbons are necessary because they are the ones providing real support of the breasts, which at the end is the purpose of a bra. Ribbons also have intermediates, and they were produced in Japan. They are made from 78 % polyester and 22% polyurethane and 74% nylon and 26% polyurethane, their weighes and measurements were also provided. Polyurethane and polyester fibers were available. The nylon textile process was also considered like the polyester one but using nylon as an input [14].

Rings and Bra adjusters

The last pieces that conform the underwear are the bra adjusters and rings, used to adjust the pieces to the body measurement of each costumer, and, needed to adapt to possible changes in the clothing item due to stretching of the ribbon. This was the hardest part to estimate, because even though the producers were spanish, the factory has closed months ago. The composition was 50% and 50% of iron and nylon and the weights were also provided. The data used didn't account the process of production since there wasn't anything similar, but it took into account the materials used.

4.2.2. Craddle to user

Sewing Workshop

To quantify the process of sewing the pieces together, a simple estimation was done. The garment is made in a sewing workshop in Madrid. This workshop has 6 people working at the same time for 8 hours a day. One out of the six workers were in charge of the whole production that was completed in a month. Taking data from the electricity needs of the workshop and supposing they equally worked the same amount of hours, the total electricity input was **60 kWh.**

Packaging

After the garmets have been sewn, they are delivered to the users. With this purpose, the brand wraps the clothing item with tissue paper and a circular sticker with the name of the brand. The wrapped product is introduced in a kraft paper box, and another sticker is placed on it to seal the box. Then, the box is introduced in a kraft envelope with bubble wrap inside.

Last Mile Delivery

Another aspect that was taken into account for the Life Cycle Assessment was the last mile delivery. This is one of the main challenges faced by the e-commerce to reduce its emissions. Going from a model where the delivery point was centralized and the route hardly changed from a decentralized model means a higher number of vans in the city, adding to delivery costs, congestion, and emissions [18].

It also makes it more difficult to estimate the impact per product, since it depends on the city where the product is delivered, and the delivery points it must pass to get to its final destination. In this case, the complexity of estimating different delivery points was excessive, so it was simplified assuming the route only had one destination point.

There are many other limitations for this type of model, for example, it doesn't take into account the purchase power of each area. Fluctuations in logistic variables are extremely difficult to estimate.

Now the challenge faced was to estimate the distance for the deliveries. Since the brand has only sold pieces in Madrid. This city, like most of the localities, has a negative gradient of population, symmetric and from the center. Since the metropolitan and surrounding areas have a shape close to a circular one, the idea was to test if the density population could follow a radial Gauss distribution. In this case, the average distance from a delivery destination could be estimated.

To test Gauss distribution theory, the tables in appendix A, where used. The methodology used was, knowing the density of a Gaussian function is:

$$\int_{-\infty}^{\infty} \phi(x)\delta x = 1\,, \phi \geq 0, \forall x \quad (2)$$

This is for a normal distribution with μ=0 and σ=1, where μ is the average, σ standard deviation and ϕ the normal distribution function. In this case the model establishes that μ, where the peak of population is found, will still be 0, and it will represent the center of the metropolitan area. Located in a map this point would be Sol. But σ, is what needs to be found in this case, and it will be a value that depends in the area. The condition that σ has to meet is:

$$\int_{\mu-\sigma}^{\mu+\sigma} \phi(x;\ \mu, \sigma)\delta x = 0{,}682 \quad (3)$$

All the previous information leads to the model:

$$\int_{-r}^{r} \phi(x; \mu;\ \sigma)\delta x = p \quad (4)$$

Where r is the distance from the center (Sol) and it is supposed to be symmetric, in the whole circular area and p is the probability to find population within this area. It is similar to the distribution function (1).

The gaussian distribution function (Φ) is represented in equation 4 and Figure 5, where u represents the value of the horizontal axis:

$$\Phi(x, \mu, \sigma) = \int_{-\infty}^{x} \phi(u; \mu; \sigma)\delta u \quad (5)$$

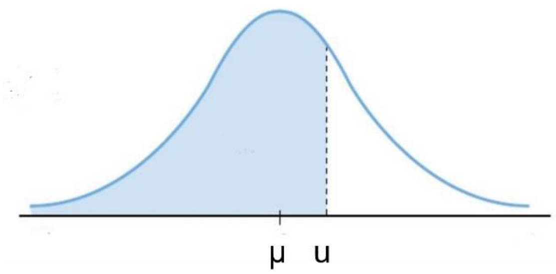


Figure 5. Normal distribution where u<$\frac{u-\mu}{\sigma}$.

Since one of the key aspects of the model is that it has to be symmetric from both sides, and this distribution isn't, taking equations (1) and (4):

$$1 - \Phi(x, \mu, \sigma) = \int_{x}^{\infty} \phi(u; \mu;\ \sigma)\delta u = \int_{-\infty}^{-x} \phi(u; \mu; \sigma)\delta u \quad (6)$$

Now introducing (5) in the model:

$$2\Phi(x, \mu, \sigma) - 1 = p \quad (7)$$

Now, that the model is defined in terms of tabulated data (Table A.1 from Appendix A), the value of σ can be estimated knowing p, the density of population in the metropolitan area of Madrid, 46.4%. This area has a radio of 13.5 km. Since the data is available for μ=0 and σ=1:

$$\Phi\left(\frac{r}{\sigma}; 0, 1\right) = \Phi(r; 0, \sigma) = \frac{p+1}{2} \quad (8)$$

The σ estimated with this data is 21.77 km. This is the limited area where the probability of finding 50% of population is. Now, taking areas A and B of Madrid (Figure 6) to check if the theory fits with the metropolitan and surrounding areas, and knowing area B has a radio of 29.5 km:

$$p = 2\Phi\left(\frac{r}{\sigma}\right) - 1 = 0{,}826 \tag{9}$$

The number obtained 82.6%, is very close to 83.9%, the density of population from areas A and B according to the literature [19].

Now that all the parameters of the model have been defined and the model itself has been verified. The estimated route has been calculated using a simple program available in the annex based on Monte Carlo integration method. This program generates 10000 random geographic coordinates and calculates their average distance to the sewing workshop. It also takes into account the wiggle factor. The average last mile delivery distance per product is 78 km.

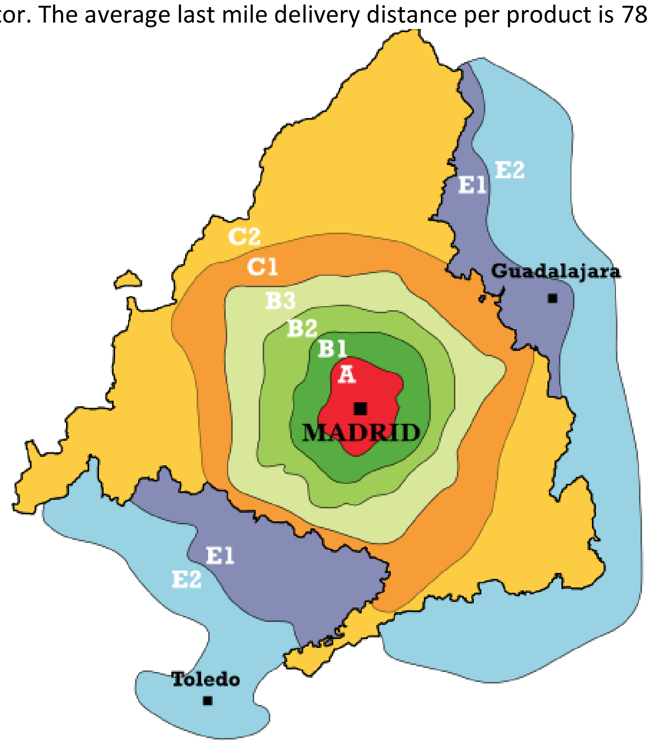


Figure 6. Different areas in Comunidad de Madrid according to the transport service **[20].**

4.2.3. Craddle to End

Use Cycle

The main impact in the use cycle of underwear, as well as in the rest of the fashion industry is its washing and other similar treatments like drying and ironing. but it was necessary to stablish a lifecycle of the clothing items. This means estimating how often they get washed and how many ears they last. Since this type of clothes are in contact with delicate areas, for hygienic reasons, it was considered that they are washed each time after their use. For the same reason, they should be changed every day, at least in the case of the bras. According to the average number of underwear, each woman buys a year (3 to 4 pairs of bras and 5 to 9 pair of briefs) and the number of pieces they have in their wardrobe (10 to 20 pairs of briefs) it is estimated that both bras and briefs last an average of **two and a half years.** This means they have an average of 65 washes if they are washed once every two weeks [21].

In this case, the impacts for this activity were taken from the Ecoinvent database. These impacts consider water, electricity, amortization of the equipments and detergents. This means, the analysis doesn't include one of the main issues of synthetic textiles use-cycle: microplastics. In fact, the washing processes of synthetic textiles are the main source of primary microplastics. It is difficult to estimate the realizing of microplastics, since they depend on the materials they are made from, the temperature, detergents, and the number of times they have been washed before. In average, the washing of this textiles means the releasing of 124 to 308 mg per kg of washed textiles, that corresponds to a number of microfibers ranging from 640000 to 1500000 [22].

End of Life Scenario

The scenario proposed for the end of the life is recycling and disposal, but since the method selected is simple cut-off the only phase that is going to be accounted in the analysis is the disposal, the recycling phase should be taken into account in the product that uses the recycled parts. Since the brand was conceived to be sustainable, it appears paradoxical considering its end-of-life cycle as “cradle to grave” instead of “cradle to cradle”, even though as it was said there is part of the material that is going to be recycled. There are three main reasons supporting this idea.

First, the Spanish normative in charge of regulation of residues and polluted soils, Law 7/2022, stablishes the obligation of selective collection of textiles. This doesn’t imply, that the collected materials are reused or recycled. In fact, MITECO has collected data from the main textile waste managers. Roba Amiga resells or donates 40%, recycles 45 %(most of them organic fabrics) and sends 15% to final treatment. Humana reuses 51%, recycles 36% and sends 13% to final treatment. Finally, AERESS reuses 64%, recycles 8%, stocks 4% and sends 24% to final treatment [23].

With all this data in mind, it seems that the most likely scenario is that all these clothes are reused. At this point, the social factor appears. First of all, the previous data represents the majority of textile waste. Clothes are disposed attending to several reasons that can be classified depending as situational factors, like changes in fashion: psychological characteristics of the owner, for example boredom or comfortless and changes in garment properties, like shrinkage, hole formation or color change [24]. Only the last one provides a reason for not reusing the item and the other two reasons are more usual in general, specially between young females and in fast fashion. But the products in this particular case don’t fit in the fast fashion category and when the clothing item is an undergarment, the tendencies change drastically, in this scenario, fashion doesn’t play a role in disposal reasons [25].Apart from the clothes conditions, the market for second-hand underwear in adults is non-existent, because of the fear of non-hygienic conditions from the previous owner [21].

For the previous reasons the preferred scenario for residues by the European Union after their reduction, reusing is discarded. The next scenario would be recycling, which means, not reusing the product but reusing the materials. In this case, the composition of the clothing item plays an important role, the more mixed a material is, the more difficult it is to recycle it. In this case, all of the lingerie parts are made from blended materials. Due to the weight and the type of materials used, since they are not the average clothing mixes used. On the other hand, Plumetti Caprice, along with the viscose lining and specially, due to its low elastane content, Saten Ecostrech could be recycled. But even though mixes with elastane are the most common and there are settled technologies to recycle the materials elastane is blended with(most of this methods require the dissolution of elastane, which means this fiber is not recycled) [26], it has been estimated that only 10% of the disposed clothes, reach clothing waste managers [27]. This is why only, the only percentage considered to be recycled is **10%.** This final stage was also available in the Ecoinvent Database.

5. Results

The analysis will cover different parts of the cycle, first, since one of the distinctive issues is the use of a fabric made out of recycled materials, it will be analysed separately. Then, there will be an analysis of the impacts of the individual pieces until the users get them and can start using them. Finally, there is an analysis of all the stages of the product including production, use and deposition.

5.1. Comparison between fabrics

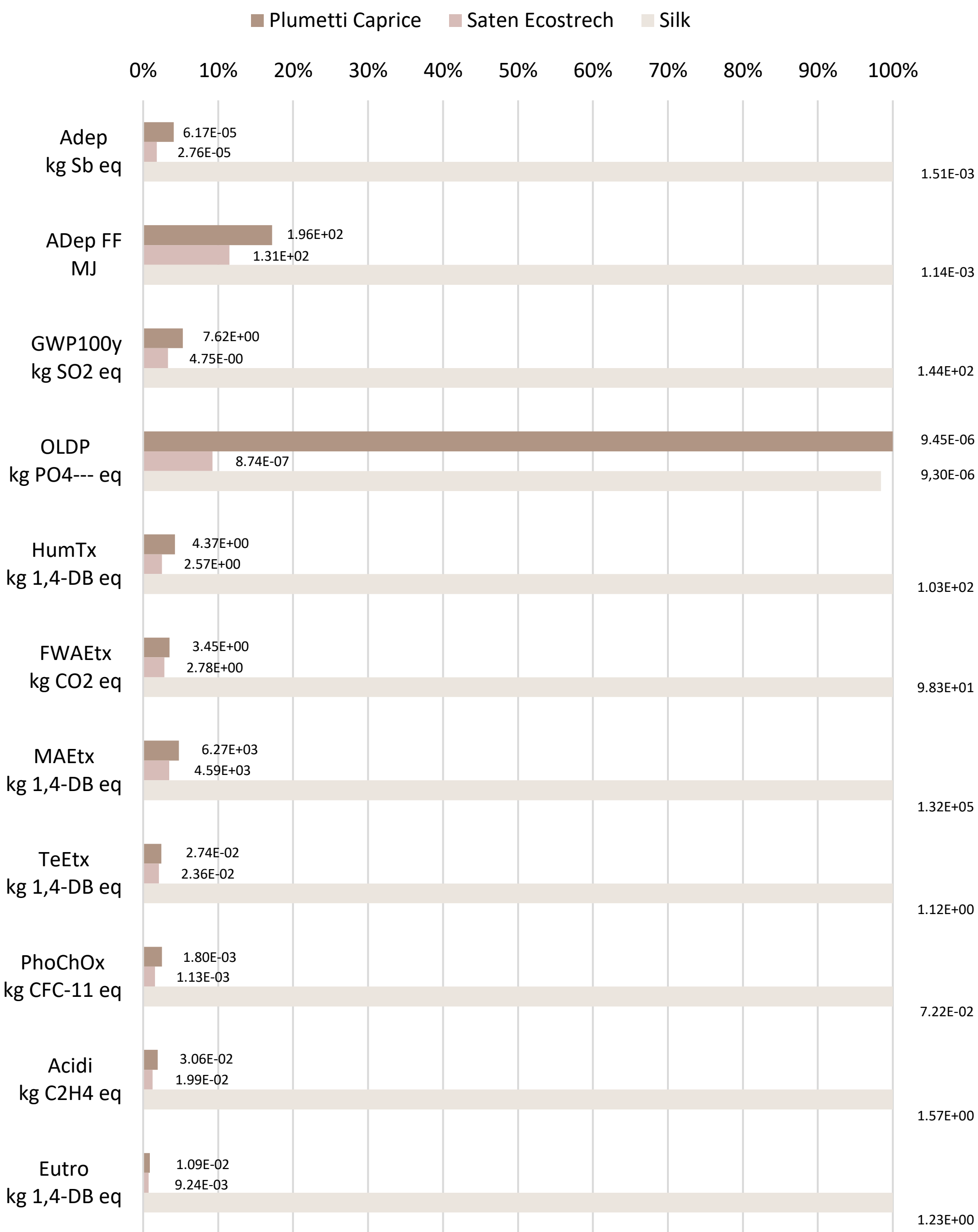
The first comparison was done between saten ecostech fabric in the different colours available, since the quantity of dye used wasn’t very significant and the only difference was in the type of disperse dyes used but there wasn’t available data about their origin and production. As it can be seen in Table 6 there is no difference between them. For this reason, from now on, the Saten Ecostrech fabric will be treated without taking into account its colour.

Table 6. Comparison of the production impacts of 1 kg of white Saten Ecostrech and black Saten Ecostrech.

Impact Category	**Units**	White Saten Ecostrech	Black Saten Ecostrech
Abiotic depletion	kg Sb eq	2.76E-05	2.76E-05
Abiotic depletion (fossil fuels)	MJ	1.31E+02	1.31E+02
Global warming (GWP100a)	kg CO_2 eq	4.75E+00	4.75E+00
Ozone layer depletion (ODP)	kg CFC^{-11} eq	8.74E-07	8.74E-07
Human toxicity	kg 1,4-DB eq	2.57E+00	2.57E+00

Impact Category	**Units**	White Saten Ecostrech	Black Saten Ecostrech
Fresh water aquatic ecotox.	kg 1,4-DB eq	2.78E+00	2.78E+00
Marine aquatic ecotoxicity	kg 1,4-DB eq	4.59E+03	4.59E+03
Terrestrial ecotoxicity	kg 1,4-DB eq	2.36E-02	2.36E-02
Photochemical oxidation	kg C_2H_4 eq	1.13E-03	1.13E-03
Acidification	kg SO_2 eq	1.99E-02	1.99E-02
Eutrophication	kg PO_4 eq	9.24E-03	9.24E-03

Now that the colour issue has been discussed, as it was mentioned earlier, the sets are made with a different fabric than the body. Both are made in the same factory with similar energy and water inputs and also similar cloth residues. The main difference between them is the raw materials used and their origin. In one case they are made out of recycled materials and the yarn providers are closer to the factory (UK and Turkey) and in the other case the providers are from China and Korea and made out of virgin polymers. Also, considering the goal of the Saten Ecostrech fabric is to give a “silky” aspect, using recycled materials and the large controversy between using organic and inorganic textile materials, 8 also includes the assessment 1kg of the average global production of silk, with data from Ecoinvent Database. The data used to represent Figures 7 and 8 is available in Table B.1 of Appendix B. overall results presented in Figure 7 show that silk has a higher impact in almost all the categories considered for the analysis is more considerable than the rest of the fabrics. This is because silk requires very special conditions for its production.



399

Figure 7. Comparison between the environmental impacts of producing 1 kg of Plumetti Pumetti Caprice, Saten Ecostrech and generic silk. 400 401

Abiotic Depletion, Abiotic Depletion of fossil fuels and global warming potential are remarkably higher in the case of silk. The contribution of Plumetti Caprice and Saten Ecostrech is 4 and 2 % in the first case, 17 and 11% for the fossil fuel category and 5 and 3% in the last case. These categories are studied together since they are related. First, the reason why there is such a big difference between silk and the man-made fibers, is that silk is produced by silkworms. These animals require a constant and controlled temperature. This explains the large use of energy and fossil fuels respectively compared with the other two fabrics. Abiotic depletion in the case of Plumetti Caprice doubles the impacts of Saten Ecostrech, because the first one doesn't contain any recycled materials. It is remarkable that the difference isn't as high as expected since 92% of the Saten Ecostrech fabric is made from recycled materials, this is because, even though the materials are recycled the origin is still plastic.

Ozone Layer Depletion is the only category where Plumetti Caprice has almost the same impact as silk, only 2% more. The reason for this category to have such different proportions from the others is that virgin polyester discharges ozone depletion substances in its manufacturing [28]. Recycled plastics have less impact in this category, therefore the impact of Saten Ecostrech is 91 % less.

The ecotoxicity categories are very high in the case of silk, because of the high amount of pesticides needed for the mulberry plants, essential for silkworms breeding. The impacts are between 95 to 98% times higher in the case of the man made fibers.

These categories don't have a high difference between the other two fabrics, even though the values are systematically higher in the case of Plumetti Caprice. Most of these categories are influenced by the manufacturing of the textile [29], for example, almost 250 liters of fresh water are required for the treatment processes. This is the reason why the differences are not very high between them, because the treatment conditions are almost the same.

Fresh water is used in the treatment processes of the fabrics. As it can be seen in the comparison is slightly lower in the case of Saten. Even when using recycled materials this means only half of the impact, since even though the life use of the plastic has been increased, it keeps coming from abiotc materials.

Something similar happens with the categories of photochemical oxidation and acidification where the impacts of Plumetti Caprice and Saten Ecostrech are 97 and 98% less and 98 and 99% less.

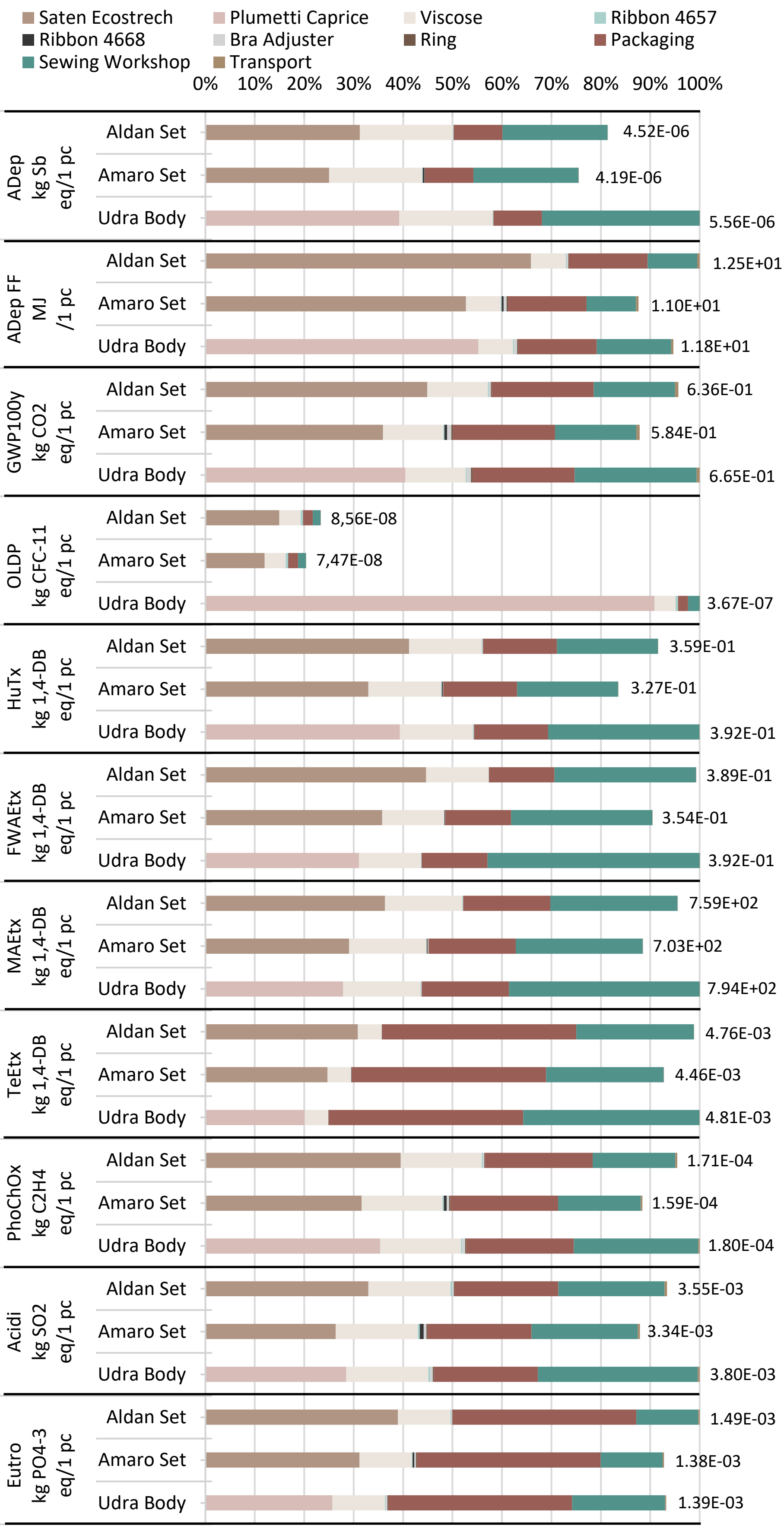
When Plumetti Caprice and Saten Ecostrech are compared to silk in the eutrophication category, they impact less than 1%. Silk causes more eutrophication due to the fertilizers used for the Mulberry plants previously mentioned.

Even though the analysis shows the environmental impact of Saten Ecostrech and Plumetti Caprice production is lower than silk, it has to be taken into account that this shows an average of the global production, and the conditions are not always the best to provide a sustainable solution. Moreover, this doesn't provide data about the end of life of the materials. If the fabric used was made entirely from silk, it would not only last longer but it would also degrade more easily for being an organic material.

5.2. Craddle to user

This part of the analysis shows the impact of each part of the production lifecycle. It has been considered for this part, the impact of the materials including the packaging and their production, the garment's ensemble. Named sewing workshop in the parameters, and the last mile delivery as transport, as it was referred in the methods section.

As it can be seen in Figure 9, there are certain pieces of the lingerie products that are almost negligible in the analysis, even though they were accounted in the process these are: the ribbons (both models), the bra adjusters and the rings, this is most likely due to the low weight these items have compared with the others. Also, the transport doesn't play an important role, due to the low mass and minimal distances they have to travel. For this reason, neither the pieces, nor the last mile delivery will be commented. Precise data of Figure 8 is available in Appendix B, Table B.2.



454

Figure 8. Comparison of materials production, life use and deposition of 1 pc of Aldan, Amaro and Udra. 455

Abiotic Depletion is 20 and 22% less in the Aldan and Amaro sets than in the udra body. This was expected due to the origin of the Saten Ecostrech and the Plumetti Caprice fabrics. From now on, in this analysis, both items will be referred as “the main fabrics”. The rest of the categories have almost the same values. This will continue to be the case since the weight of the secondary materials is almost the same if not the same in many cases.

Abiotic Depletion of Fossil Fuels shows a higher impact in Aldan, precisely 5% more than in the Udra Body and 12% compared to Amaro. The energy demand for the fabric production is higher in the Aldan and Amaro sets 66 and 60% compared to the 58% of the Udra Body, mostly due because of the higher grammage of the first pieces, but the energy needs for the garment ensemble are higher in the last case 10 and 11% compared to 16%.

Global warming potential’s distribution is more balanced and even though the higher share belongs to the main fabrics with 47. 41 and 40% for Aldan, Amaro and Udra, higher for the body Udra and 4 and 12% less for Aldan and Amaro sets. The other categories are very balanced between them and their contribution to the total impact is similar. This doesn’t align, in the case of the materials, totally with the weight, because the material with the higher mass is the packaging, but the emissions from its production are less.

Once again, the most noticeable difference between the three items is in the ozone layer depletion, where the impact of the sets made out of Saten Ecostrech is 75 and 80% less than in the Udra Body’s case. This is due to processes related to manufacturing polyester, that in the Udra’s case is more significant than in the Aldan and Amaro sets. This category has a lot in common with the global warming potential one and the abiotic depletion, since the components that affects the most the ozone layer depletion are the CFC and HFC and they have a large GWP coefficient.

The impacts of human toxicity are 8% less in the Aldan set than in the Udra Body and 16% for the Amaro. They have a similar share in each category, and the principal impacts come from the main fabric manufacturing 45, 39 and 39% for the Aldan, Amaro and Udra and from the sewing workshop 22, 24 and 31% (in the same order).

Fresh water ecotoxicity is very similar in the three cases. For Udra body and Aldan set is almost the same and in the case of the Amaro is almost 10% less than in the other cases. There is a big difference about what stages are increasing the value of this impact. In the case of the Aldan (and the Amaro) sets most of the share comes from the manufacturing of the main fabric, (45, 40 and 31% for Aldan, Amaro and Udra) And in the case of the Udra body, the sewing workshop represents a 43%, while for the Aldan and Amaro sets it is 29 and 32%.

Something similar happens in the case of marine ecotoxicity where Aldan and Amro only have a difference of 4% and the Amaro’s impact is only 12% less than Aldan. The most influential stage in the first one is the production of the fabric 38 and 33% for the Aldan and Amaro, while in the Udra Body it means a 28% and in the sewing workshop the contribution of the Udra body is 39%, while the contribution from Aldan and Amaro sets is 27 and 29%.

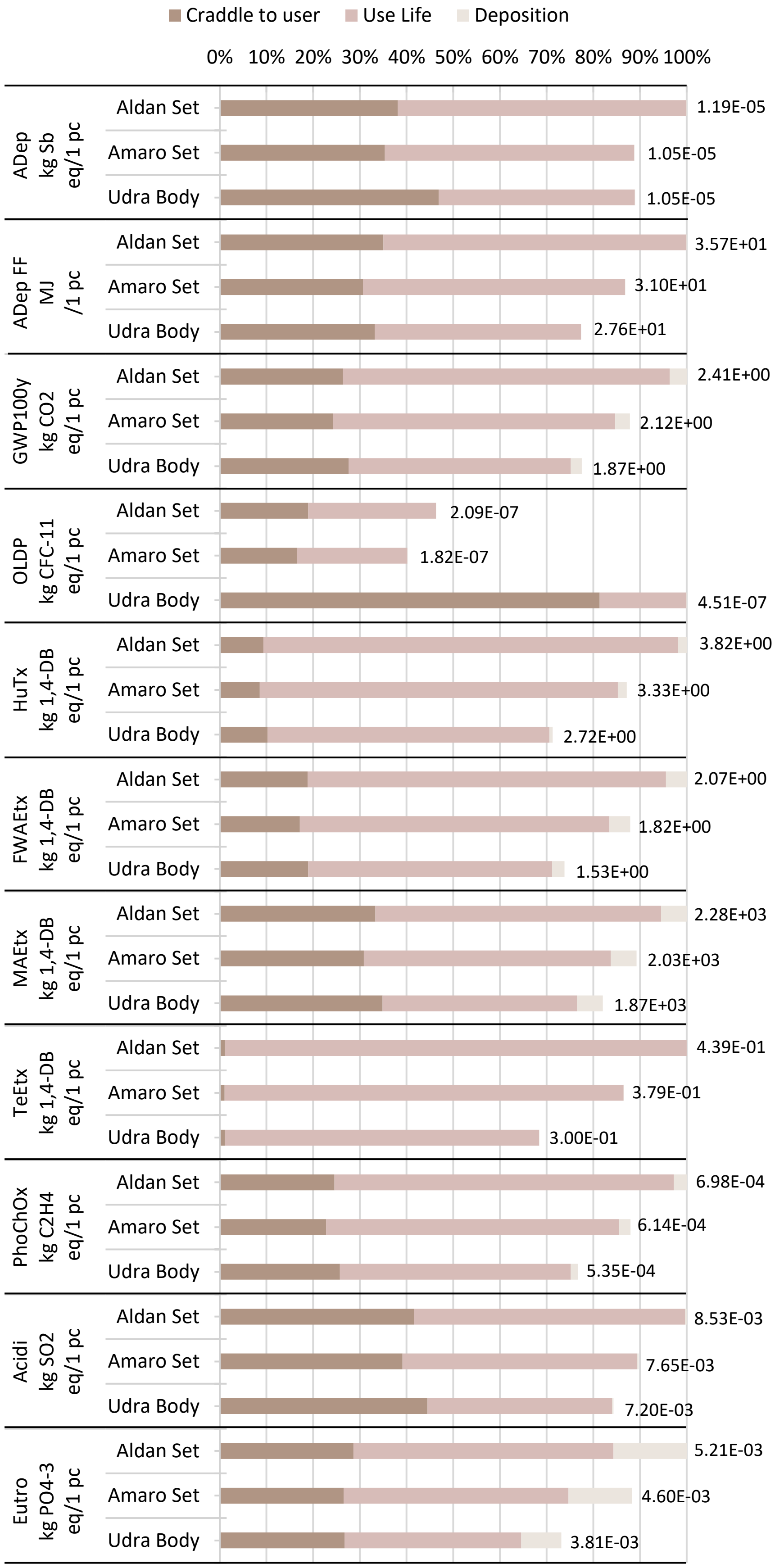
Terrestrial ecotoxicity is one of the most balanced categories and it is one of the most dependent on weight. Aldan and Udra body have almost the same impact 99 and 100%, because, even though the weight is higher in the first place, and it requires more material, it is compensated in the extra work needed for the body in the sewing workshop. Amaro’s values aren’t far either, only 7% less than the Udra body.

Photochemical oxidation and acidification have very similar values, main fabrics are around 30 to 40%, viscose is 17-19%, packaging is 21-25% and the sewing workshop 20-30%. This might be due to the energy requirements also and the emissions from fossil fuels.

Eutrophication has similar results as terrestrial ecotoxicity 37% for Aldan and 40% for both Amaro and Udra. The reason for this being such an important share in this category is that kraft paper comes from an organic material that requires fertilizers for its growth, these fertilizers are causing the eutrophication in other ecosystems. Even though, its weight is lower, viscose also has a bigger share in this category, of 11%, for the same reasons.

5.3. Craddle to end

This scenario, available in Figure 9 completes the analysis showing the impact of washing and final deposition of each one of the items, compared to their production.



510

Figure 9. Comparison of production, life use and deposition of 1 pc of Aldan, Amaro and Udra. 511

As it can be seen in Figure 9, and in the Table B.3. from Appendix B, the comparison between the three phases accounted attributes the impacts mostly to the use phase of the clothing piece instead of the production. This is happening because the washing of the item is frequent, and it happens 78 times in the entire life of the clothing item. This means washing the item only one time has 78 times less impact. The disposal phase has minimal impacts, even though landfills have negative impacts, the weight of one of these pieces compared to the total capacity of the landfill is almost negligible.

When the different products are compared, it is noticeable that the item with higher impacts in most categories is the Aldan set followed by the Amaro set. This also happened before because the weight of each clothing piece is crucial. The disposal and use phases also depend on this parameter.

Abiotic depletion is 11% higher for Aldan Set when compared to the other two that share the same value by chance. In this case both, Aldan and Amaro set have similar contributions for each phase, 38% and 40% of the contribution is due to production in Aldan and Amaro sets respectively, 0% to deposition and the rest corresponds to the use cycle. In the Udra body, the proportions are different, and the production means 53% of the share. This is what was estimated to happen when using virgin materials.

Abiotic depletion of fossil fuels is more balanced and determined because of the weights, with Aldan being the item with biggest impact and the Amaro and Udra sets having 12 and 22 % less impact. Once again, the contribution of both sets is similar for the different stages, as it is going to keep happening for the rest of the categories, the production is 35% in both cases and in the case of the Udra Body this ascends to 43%.

Global warming potential as it was discussed in the rest of the analysis is very similar to the last one, since typically the greenhouse gases come from the combustion of fossil fuels, so it also has similar results, but in this case the final deposition stage is more noticeable than in the rest of the categories. Even though it only means 4% in the cases of the Amaro and Aldan sets and 3% in the body Udra. This is because this category, unlike the last one, takes into account emissions. Since the last one only considers the energy use of the pieces and there is none in the landfill, it makes sense that deposition has 0% impact in the last category, but there are emissions.

The ozone layer depletion has been consistently higher in the case of the body Udra along the whole study and the last step isn’t an exception. The contribution of Aldan and Amaro sets are 55 and 60% less. This difference is mostly due to the production phase, that means an 80% of the total contribution.

In the four following categories that refer to toxicity the weight of the impact of each set is very similar and it follows the sequence Aldan, Amaro and Udra in all three cases. Human toxicity presents a very high share of the impact, 89, 88 and 88 % of the impact for Aldan, Amaro and Udra. And also, depletion category is slightly noticeable but it means 2 % for Amaro and Aldan and 1% for Udra. Freshwater ecotoxicity has similar results but with higher shares of the production and the deposition stages (19, 19 and 26%) and (4, 5 and 4%) for Aldan Amaro and Udra. The same happens with Marine Toxicity with the contributions even more balanced in the Aldan, Amaro and Udra pieces: production means 33, 35 and 43 % and deposition 5, 6 and 7 %.

Terrestrial Ecotoxicity presents very different results, in this category in particular the share of the use cycle is very high, it means 99 and 98% in the Aldan and Amaro and Udra, and the rest only corresponds to production. These results are due to the high use of detergents [31].

Photochemical oxidation presents 73, 71 and 64% of the total share dedicated to use phase and 3, 3 and 2% dedicated to deposition and acidification has a similar rate in production and use stages and no impact in deposition. This makes sense since wastewater is one of the most influential parameters in this category [31] and the first two stages require a large mass of water that isn’t recirculated (mostly) and in the landfills the control over the leachate is very high so it doesn’t transfer to aquifers, this makes the wastewater production minimal in this stage.

Finally, the eutrophication category has similar results than the ones for “water categories”. One more time the biggest contribution is given from the use cycle 56, 54 and 52%. There is a link between eutrophication and the use of detergents since they usually contain phosphates. But also, this is the category where the landfill stage is more important. It means 16, 15 and 12%. This also might be likely because the degradation of the materials to more simple compounds, that can be used as nutrients.

5. Discussion

One of the advantages of making this type of studios for a brand is it provides a lot of data about where are the biggest impacts and it allows the brand owner to set a starting point to make improvements. The fact that it provides this amount of data, hinders the decision-making process, since there are multiple variables to take into account. It also makes the information less easy to understand to the general public, which at the end is one of the goals of making the study. This is why, many companies decide to simplify their studies focusing in only one variable: the global warming potential. Not because it is considered to be more "important" than the rest of them, but because the indicator used, CO_2 emissions is more commonly known and also, because of the social alarm produced by climate change. This is probably the most discussed category by the public.

Another of the challenges when giving this information to the public is that even though a number can be provided, there is a lack of bias about what this number means exactly, since there are not many brands nowadays being transparent about their own carbon footprint. Luckily, for this purpose there was one brand providing this information: closely [32]. This brand publishes the carbon footprint of its clothing items. The ones selected were the ones with the closest design compared with the brand. Also, it should be noted that the brand didn't specify the scope of the analysis, it is unknown if it is cradle to grave, or cradle to gate… It was assumed that it was cradle to grave since it is the most typical assessment.

Table 7 shows that the values are comparable with a sustainable brand, the impacts are 12-22% less in the case of the sets for RÚA Intimates. These was the one made with the recycled fabric. In the case of the free bra these contained recycled materials but with a lower share (71% in the microfiber, 46% in the straps and 63% in the elastics). In the case of the Udra Body, that wasn't made with recycled materials, the emissions from the RÚA Intimates product are 26% less. Lace and elastics in the closely case are made from 41% and 63% recycled materials respectively while Udra body didn't contain any recycled materials. The fact that the company also gives data about the materials of the clothing items means that they've also detected a big impact from the main fabrics production stage.

Table 7. Global warming potential from cradle to grave perspective from closely and the RÚA Intimates classified by type of clothing item in kg CO_2 eq.

The RÚA Intimates GWP(kg CO_2 eq)		Closely GWP(kg CO_2 eq)
Aldán	**Amaro**	**Free set**
2.41	2.12	2.71
Udra body		**Bird body**
1.87		1.39

Improvements

The main challenge to propose improvements for a starting brand like the one proposed is the lack of means to change the production, since it depends on the providers, and even tough costumers are a major force to implement changes in companies, the weight of this costumers has to be high enough to induce these changes. One of the initial thoughts could be that if the providers don't have the best performance, they could be changed to other ones, but the fact is, it is very difficult to find sustainable fabric providers for purposes as specific as lingerie, this is one of the disadvantages of the innovative idea of creating a small sustainable lingerie brand. Two of the principal materials that could be easily replaced are the lining, instead of viscose, use Tencel, that has very similar features and it is design with the aim of being more sustainable and the ribbons used. The materials used for the ribbons are very common and providers offering similar characteristics could be found closer to the destination. The rings and bra adjusters used until the moment are being discontinued since the providers closed their factory, so this also could be a chance for the brand to find something with less impact, even though as it could be seen in the results, the difference they cause compared to the other materials is not significant. However, bra adjusters could be replaced as metallic pieces without the nylon coverage, so this part could be recycled entirely, and the use of the rings could be changed by using a folded ribbon.

The changes applied to the production process could be from getting the fibers from a closer location, using recycled materials in all their production line, offering monomaterial fabrics, that make it easier to recycle in the end life of these products, install solar panels to provide the energy required for the factory and change the natural gas boiler for one that uses biofuels. If the brand is conceived to be sustainable, the providers should be sustainable as well. These improvements, however, don't depend directly on the brand.

The next step after producing the clothing items is the last delivery mile. The last delivery mile emissions could be significantly reduced if the float used to send the packages was electrified, this type of shipments are not very frequent in Madrid yet, but they are some pilot projects in the city, that could make this option feasible very soon [33].

Another of the biggest challenges for clothing apparel that comes from synthetic fibers, as it was mentioned is the releasing of microfibers into water ecosystems. This is an issue very difficult to avoid. There are some available technologies that can prevent the realizing of microfibers. Some are external devices attached to the washing machine and others, like the ones proposed are laundry bags that retain the pollutants. All of them have been tested and the last ones, with the commercial names of *Guppyfriend* and *XFiltra* apart from being more affordable have the best performance results capturing microfibers [34].They could be added and used as packaging for the brand, even though this would increase costs.

As it was mentioned in previous parts of this study, before considering reusing or recycling the pieces of clothing, the first step could be reducing waste. Therefore, one of the improvements proposed for the brand is offer a reparation service. This means, after two and a half years the brand, for a minimum price could replace the pieces that typically get more damage from the use, such as elastic parts and the viscose lining, this last one for hygienic reasons, so the costumer could keep using it. This would extend the life cycle of the items and at the same time, encourage customers to reuse underwear clothing without the fear mentioned earlier of it not being hygienic enough.

The last improvement idea is that the brand provides information to the costumer. Not only sharing the impacts of the product in a way that is understandable for the consumer, but also, focus on the costumer behaviors to reduce their ecological footprint when using the products and similar ones. There are multiple solutions and creative ways to provide information that shocks the costumer and informs them at the same time, for example, represent the mass of the emissions in the number of clothing items they equal to, or compare the total emissions to the quantity of CO_2 a person exhales.

7. Conclusions

The studio has fulfilled the objectives listed on the beginning of tracing the environmental footprint of the production of the brand. The brand has reached the goal of successful environmental performance at the same time as it has been able to provide the most desired characteristics in a lingerie set (comfort and quality) until the moment, but sustainability must consist in a constant improvement that inevitably relies on scientific innovation and efficiency improvement. It has also been proven that the impacts are less significant than if the pieces were made from silk.

The results have shown that even though there were clear differences in the raw materials used for each piece, the impacts were very similar in all the clothing items, even higher in the case of recycled clothes. As it was explained throughout all the analysis this is mainly because of the weight difference between the clothes. Taking into consideration that varying this parameter is what caused the most significant differences could mislead the reader into thinking that making less weighted clothing pieces is the key to solve the fashion industry impacts. Unfortunately, it doesn't work this way. It is true that using less amount of virgin plastics, reduces the impact of abiotic depletion, but the quantity and composition of the fabric also affects the grammage and other properties of the clothing item, and sometimes these properties can't be changed because they affect other parameter as the temperature comfort they provide, which is the reason why clothes are worn in the first place, (apart from moral reasons), or even their durability. Apart from these reasons when the production is very high, the volume of the items becomes more important since it has to be storage and transported. This is why, as it was shown in the first analysis, when the fabrics where compared, it is more important to use the raw materials with the least impact and make the processes as efficient as possible.

From the results, it was very difficult to tell where the different phases and materials were going to have an impact. This shows the lack of knowledge from the background processes taking place in each of the stages, or as they have been called recently: the externalized costs.

Apart from the performative value of the brand, the lack of transparency and information about the processes and the environmental impacts of the products coming from the different providers, make it very difficult to make an analysis for a small brand.

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Appendix A. Last mile Delivery Estimation.

Table A1. Normal distribution.

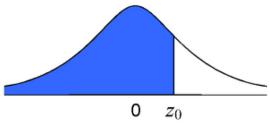
Tabla de la distribución normal N(0,1) para probabilidad acumulada inferior

μ = Media

σ = Desviación típica

$$P(z \le z_0) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z_0} e^{\frac{-z^2}{2}} dz$$

Tipificación: $z_0 = \frac{x-\mu}{\sigma}$



z_0	0,00	0,01	0,02	0,03	0,04	0,05	0,06	0,07	0,08	0,09	z_0
0,0	0,5000	0,5040	0,5080	0,5120	0,5160	0,5199	0,5239	0,5279	0,5319	0,5359	**0,0**
0,1	0,5398	0,5438	0,5478	0,5517	0,5557	0,5596	0,5636	0,5675	0,5714	0,5753	**0,1**
0,2	0,5793	0,5832	0,5871	0,5910	0,5948	0,5987	0,6026	0,6064	0,6103	0,6141	**0,2**
0,3	0,6179	0,6217	0,6255	0,6293	0,6331	0,6368	0,6406	0,6443	0,6480	0,6517	**0,3**
0,4	0,6554	0,6591	0,6628	0,6664	0,6700	0,6736	0,6772	0,6808	0,6844	0,6879	**0,4**
0,5	0,6915	0,6950	0,6985	0,7019	0,7054	0,7088	0,7123	0,7157	0,7190	0,7224	**0,5**
0,6	0,7257	0,7291	0,7324	0,7357	0,7389	0,7422	0,7454	0,7486	0,7517	0,7549	**0,6**
0,7	0,7580	0,7611	0,7642	0,7673	0,7704	0,7734	0,7764	0,7794	0,7823	0,7852	**0,7**
0,8	0,7881	0,7910	0,7939	0,7967	0,7995	0,8023	0,8051	0,8078	0,8106	0,8133	**0,8**
0,9	0,8159	0,8186	0,8212	0,8238	0,8264	0,8289	0,8315	0,8340	0,8365	0,8389	**0,9**
1,0	0,8413	0,8438	0,8461	0,8485	0,8508	0,8531	0,8554	0,8577	0,8599	0,8621	**1,0**
1,1	0,8643	0,8665	0,8686	0,8708	0,8729	0,8749	0,8770	0,8790	0,8810	0,8830	**1,1**
1,2	0,8849	0,8869	0,8888	0,8907	0,8925	0,8944	0,8962	0,8980	0,8997	0,9015	**1,2**
1,3	0,9032	0,9049	0,9066	0,9082	0,9099	0,9115	0,9131	0,9147	0,9162	0,9177	**1,3**
1,4	0,9192	0,9207	0,9222	0,9236	0,9251	0,9265	0,9279	0,9292	0,9306	0,9319	**1,4**
1,5	0,9332	0,9345	0,9357	0,9370	0,9382	0,9394	0,9406	0,9418	0,9429	0,9441	**1,5**
1,6	0,9452	0,9463	0,9474	0,9484	0,9495	0,9505	0,9515	0,9525	0,9535	0,9545	**1,6**
1,7	0,9554	0,9564	0,9573	0,9582	0,9591	0,9599	0,9608	0,9616	0,9625	0,9633	**1,7**
1,8	0,9641	0,9649	0,9656	0,9664	0,9671	0,9678	0,9686	0,9693	0,9699	0,9706	**1,8**
1,9	0,9713	0,9719	0,9726	0,9732	0,9738	0,9744	0,9750	0,9756	0,9761	0,9767	**1,9**
2,0	0,9772	0,9778	0,9783	0,9788	0,9793	0,9798	0,9803	0,9808	0,9812	0,9817	**2,0**
2,1	0,9821	0,9826	0,9830	0,9834	0,9838	0,9842	0,9846	0,9850	0,9854	0,9857	**2,1**
2,2	0,9861	0,9864	0,9868	0,9871	0,9875	0,9878	0,9881	0,9884	0,9887	0,9890	**2,2**
2,3	0,9893	0,9896	0,9898	0,9901	0,9904	0,9906	0,9909	0,9911	0,9913	0,9916	**2,3**
2,4	0,9918	0,9920	0,9922	0,9925	0,9927	0,9929	0,9931	0,9932	0,9934	0,9936	**2,4**
2,5	0,9938	0,9940	0,9941	0,9943	0,9945	0,9946	0,9948	0,9949	0,9951	0,9952	**2,5**
2,6	0,9953	0,9955	0,9956	0,9957	0,9959	0,9960	0,9961	0,9962	0,9963	0,9964	**2,6**
2,7	0,9965	0,9966	0,9967	0,9968	0,9969	0,9970	0,9971	0,9972	0,9973	0,9974	**2,7**
2,8	0,9974	0,9975	0,9976	0,9977	0,9977	0,9978	0,9979	0,9979	0,9980	0,9981	**2,8**
2,9	0,9981	0,9982	0,9982	0,9983	0,9984	0,9984	0,9985	0,9985	0,9986	0,9986	**2,9**
3,0	0,99865	0,99869	0,99874	0,99878	0,99882	0,99886	0,99889	0,99893	0,99896	0,99900	**3,0**
3,1	0,99903	0,99906	0,99910	0,99913	0,99916	0,99918	0,99921	0,99924	0,99926	0,99929	**3,1**
3,2	0,99931	0,99934	0,99936	0,99938	0,99940	0,99942	0,99944	0,99946	0,99948	0,99950	**3,2**
3,3	0,99952	0,99953	0,99955	0,99957	0,99958	0,99960	0,99961	0,99962	0,99964	0,99965	**3,3**
3,4	0,99966	0,99968	0,99969	0,99970	0,99971	0,99972	0,99973	0,99974	0,99975	0,99976	**3,4**
3,5	0,99977	0,99978	0,99978	0,99979	0,99980	0,99981	0,99981	0,99982	0,99983	0,99983	**3,5**
3,6	0,99984	0,99985	0,99985	0,99986	0,99986	0,99987	0,99987	0,99988	0,99988	0,99989	**3,6**
3,7	0,99989	0,99990	0,99990	0,99990	0,99991	0,99991	0,99992	0,99992	0,99992	0,99992	**3,7**
3,8	0,99993	0,99993	0,99993	0,99994	0,99994	0,99994	0,99994	0,99995	0,99995	0,99995	**3,8**
3,9	0,99995	0,99995	0,99996	0,99996	0,99996	0,99996	0,99996	0,99996	0,99997	0,99997	**3,9**

$1-\alpha$	90%	92%	94%	95%	96%	97%	98%	99%
α	10%	8%	6%	5%	4%	3%	2%	1%
$z_{\alpha/2}$	1,645	1,751	1,881	1,960	2,054	2,170	2,326	2,576
z_α	1,282	1,405	1,555	1,645	1,751	1,881	2,054	2,326

Siendo:

$1-\alpha$ = Nivel de confianza

α = Nivel de significación

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```
import numpy as np

sigma=21.9
mu=0
sewing_workshop_x=18.8
sewing_workshop_y=21.7
radio=45 #Area C1: 45, area E: 64

N = 10000
total_distance=0
number_points=0
for i in range(N):
    x = sigma*np.random.randn()
    y = sigma*np.random.randn()
    distance_center = np.sqrt(x**2+y**2)
    if distance_center<=radio:
        distance_sewing_workshop   =   np.sqrt((x-sewing_workshop_x)**2+(y-sew-
ing_workshop_y)**2)
        total_distance = total_distance + distance_sewing_workshop
        number_points = number_points+1
straight_distance = total_distance/number_points
wiggle_factor = 2
wiggle_distance = straight_distance*wiggle_factor

print("Distance: ", wiggle_distance)
for i in range(N):
    x = sigma*np.random.randn()
    y = sigma*np.random.randn()
    distance_center = np.sqrt(x**2+y**2)
```

Figure A.1. Python program used to estimate the last mile delivery.

Appendix B. Results

Table B.1. Comparison between the environmental impacts of producing 1 kg of Plumetti Caprice, Saten Ecostrech and Silk.

Impact Category	Units	Plumetti Caprice	Saten Ecostrech	Silk
ADep	kg Sb eq	6.17E-05	2.76E-05	1.51E-03
ADep FF	MJ	1.96E+02	1.31E+02	1.14E+03
GWP100y	kg CO_2 eq	7.62E+00	4.75E+00	1.44E+02
OLDP	kg CFC^{-11} eq	9.45E-06	8.74E-07	9.30E-06
HumTx	kg 1,4-DB eq	4.37E+00	2.57E+00	1.03E+02
FWAEtx	kg 1,4-DB eq	3.45E+00	2.78E+00	9.83E+01
MAEtx	kg 1,4-DB eq	6.27E+03	4.59E+03	1.32E+05
TeEtx	kg 1,4-DB eq	2.74E-02	2.36E-02	1.12E+00
PhoChOx	kg C_2H_4 eq	1.80E-03	1.13E-03	7.22E-02
Acidi	kg SO_2 eq	3.06E-02	1.99E-02	1.57E+00
Eutro	kg PO_4 eq	1.09E-02	9.24E-03	1.23E+00

Table B.2. Comparison between the environmental impacts of producing 1 pieces of the Aldan set, Amaro set and Udra body, including all the production process of the garments, the sewing process and the last mile delivery.

Categoría de impacto		Saten Ecostrech	Plumetti Caprice	Viscose	Ribbon 4657	Ribbon 4668	Bra Adjuster	Ring	Packaging	Transport	Sewing Workshop
ADep kg Sb eq/1 pc	Aldan Set	1.74E-06	0.00E+00	1.05E-06	7.52E-09	0.00E+00	1.39E-09	5.91E-10	5.46E-07	1.88E-10	1.18E-06
	Amaro Set	1.39E-06	0.00E+00	1.05E-06	7.52E-09	1.88E-08	2.78E-09	1.18E-09	5.46E-07	1.77E-10	1.18E-06
	Udra Body	0.00E+00	2.18E-06	1.05E-06	7.52E-09	0.00E+00	2.78E-09	1.18E-09	5.46E-07	1.64E-10	1.77E-06
ADep FF MJ/1 pc	Aldan Set	8.24E+00	0.00E+00	8.82E-01	2.50E-02	0.00E+00	3.75E-02	1.59E-02	1.99E+00	6.62E-02	1.25E+00
	Amaro Set	6.60E+00	0.00E+00	8.82E-01	2.50E-02	4.91E-02	7.49E-02	3.18E-02	1.99E+00	6.25E-02	1.25E+00
	Udra Body	0.00E+00	6.91E+00	8.82E-01	2.50E-02	0.00E+00	7.49E-02	3.18E-02	1.99E+00	5.79E-02	1.88E+00
GWP100y kg CO_2 eq/1 pc	Aldan Set	2.99E-01	0.00E+00	8.12E-02	1.46E-03	0.00E+00	2.72E-03	1.15E-03	1.37E-01	4.67E-03	1.09E-01
	Amaro Set	2.39E-01	0.00E+00	8.12E-02	1.46E-03	3.89E-03	5.44E-03	2.31E-03	1.37E-01	4.41E-03	1.09E-01
	Udra Body	0.00E+00	2.69E-01	8.12E-02	1.46E-03	0.00E+00	5.44E-03	2.31E-03	1.37E-01	4.09E-03	1.64E-01
OLDP kg CFC-11 eq/1 pc	Aldan Set	5.50E-08	0.00E+00	1.57E-08	1.85E-09	0.00E+00	4.56E-12	1.94E-12	7.21E-09	9.54E-12	5.80E-09
	Amaro Set	4.40E-08	0.00E+00	1.57E-08	1.85E-09	1.36E-10	9.13E-12	3.87E-12	7.21E-09	9.01E-12	5.80E-09
	Udra Body	0.00E+00	3.34E-07	1.57E-08	1.85E-09	0.00E+00	9.13E-12	3.87E-12	7.21E-09	8.35E-12	8.70E-09

Categoría de impacto		Saten Ecostrech	Plumetti Caprice	Viscose	Ribbon 4657	Ribbon 4668	Bra Adjuster	Ring	Packaging	Transport	Sewing Workshop
HuTx kg 1,4-DB eq/1 pc	Aldan Set	1.62E-01	0.00E+00	5.77E-02	6.50E-04	0.00E+00	1.80E-04	7.65E-05	5.85E-02	1.62E-04	8.00E-02
	Amaro Set	1.29E-01	0.00E+00	5.77E-02	6.50E-04	5.27E-04	3.61E-04	1.53E-04	5.85E-02	1.53E-04	8.00E-02
	Udra Body	0.00E+00	1.54E-01	5.77E-02	6.50E-04	0.00E+00	3.61E-04	1.53E-04	5.85E-02	1.42E-04	1.20E-01
FWAEtx kg 1,4-DB eq/1 pc	Aldan Set	1.75E-01	0.00E+00	4.92E-02	3.29E-04	0.00E+00	9.99E-05	4.24E-05	5.21E-02	2.11E-05	1.12E-01
	Amaro Set	1.40E-01	0.00E+00	4.92E-02	3.29E-04	2.58E-04	2.00E-04	8.48E-05	5.21E-02	1.99E-05	1.12E-01
	Udra Body	0.00E+00	1.22E-01	4.92E-02	3.29E-04	0.00E+00	2.00E-04	8.48E-05	5.21E-02	1.84E-05	1.68E-01
MAEtx kg 1,4-DB eq/1 pc	Aldan Set	2.89E+02	0.00E+00	1.24E+02	8.32E-01	0.00E+00	6.74E-01	2.86E-01	1.40E+02	7.92E-02	2.04E+02
	Amaro Set	2.31E+02	0.00E+00	1.24E+02	8.32E-01	9.27E-01	1.35E+00	5.72E-01	1.40E+02	7.48E-02	2.04E+02
	Udra Body	0.00E+00	2.21E+02	1.24E+02	8.32E-01	0.00E+00	1.35E+00	5.72E-01	1.40E+02	6.93E-02	3.06E+02
TeEtx kg 1,4-DB eq/1 pc	Aldan Set	1.48E-03	0.00E+00	2.30E-04	2.09E-06	0.00E+00	2.78E-07	1.18E-07	1.89E-03	3.59E-06	1.14E-03
	Amaro Set	1.19E-03	0.00E+00	2.30E-04	2.09E-06	2.43E-06	5.57E-07	2.36E-07	1.89E-03	3.39E-06	1.14E-03
	Udra Body	0.00E+00	9.66E-04	2.30E-04	2.09E-06	0.00E+00	5.57E-07	2.36E-07	1.89E-03	3.14E-06	1.71E-03
PhoChOx kg C_2H_4 eq/1 pc	Aldan Set	7.09E-05	0.00E+00	2.94E-05	5.13E-07	0.00E+00	4.60E-07	1.95E-07	3.91E-05	6.29E-07	3.01E-05
	Amaro Set	5.68E-05	0.00E+00	2.94E-05	5.13E-07	9.79E-07	9.21E-07	3.91E-07	3.91E-05	5.94E-07	3.01E-05
	Udra Body	0.00E+00	6.35E-05	2.94E-05	5.13E-07	0.00E+00	9.21E-07	3.91E-07	3.91E-05	5.50E-07	4.52E-05
Acidi kg SO_2 eq/1 pc	Aldan Set	1.25E-03	0.00E+00	6.32E-04	1.58E-05	0.00E+00	9.97E-06	4.23E-06	7.99E-04	1.80E-05	8.18E-04
	Amaro Set	1.00E-03	0.00E+00	6.32E-04	1.58E-05	2.96E-05	1.99E-05	8.46E-06	7.99E-04	1.70E-05	8.18E-04
	Udra Body	0.00E+00	1.08E-03	6.32E-04	1.58E-05	0.00E+00	1.99E-05	8.46E-06	7.99E-04	1.58E-05	1.23E-03
Eutro kg PO_4^{-3} eq/1 pc	Aldan Set	5.81E-04	0.00E+00	1.58E-04	2.47E-06	0.00E+00	2.60E-06	1.10E-06	5.55E-04	4.07E-06	1.87E-04
	Amaro Set	4.65E-04	0.00E+00	1.58E-04	2.47E-06	4.71E-06	5.21E-06	2.21E-06	5.55E-04	3.84E-06	1.87E-04
	Udra Body	0.00E+00	3.84E-04	1.58E-04	2.47E-06	0.00E+00	5.21E-06	2.21E-06	5.55E-04	3.56E-06	2.81E-04

Table B.3. Comparison between the environmetal impacts of the life cycle of1 piece of Aldan set, Amaro set and Udra body, including all the production process of the garments, the sewing process and the last mile

Categoría de impacto		Craddle to user	Use Life	Deposition	TOTAL
ADep (kg Sb eq/1 pc)	Aldan Set	4.52E-06	7.32E-06	8.39E-09	1.19E-05
	Amaro Set	4.19E-06	6.33E-06	8.43E-09	1.05E-05
	Udra Body	5.56E-06	4.98E-06	6.11E-09	1.05E-05
ADep FF (MJ/1 pc)	Aldan Set	12.513008	23.18266	0.02303145	3.57E+01
	Amaro Set	10.962884	20.034535	0.0225856	3.10E+01
	Udra Body	11.848806	15.76788	0.02320231	2.76E+01
GWP100y (kg CO_2 eq/1 pc)	Aldan Set	0.63638818	1.6864536	0.08783989	2.41E+00
	Amaro Set	0.58418359	1.457439	0.07593387	2.12E+00
	Udra Body	0.66487431	1.1470555	0.05778182	1.87E+00
OLDP (kg CFC-11 eq/1 pc)	Aldan Set	8.56E-08	1.23E-07	3.77E-10	2.09E-07
	Amaro Set	7.47E-08	1.07E-07	3.70E-10	1.82E-07
	Udra Body	3.67E-07	8.39E-08	2.53E-10	4.51E-07
HuTx (kg 1,4-DB eq/1 pc)	Aldan Set	0.35892525	3.3898064	0.07259263	3.82E+00
	Amaro Set	0.32739205	2.9294824	0.07276766	3.33E+00
	Udra Body	0.39197514	2.3056051	0.02640778	2.72E+00
FWAEtx (kg 1,4-DB eq/1 pc)	Aldan Set	0.38908727	1.5879052	0.09151857	2.07E+00
	Amaro Set	0.35445704	1.3722732	0.09119799	1.82E+00
	Udra Body	0.39196479	1.080027	0.05569696	1.53E+00
MAEtx (kg 1,4-DB eq/1 pc)	Aldan Set	758.6765	1393.2347	124.95347	2.28E+03
	Amaro Set	702.81847	1204.0383	125.41008	2.03E+03
	Udra Body	794.37116	947.62023	126.3371	1.87E+03
TeEtx (kg 1,4-DB eq/1 pc)	Aldan Set	0.00475669	0.43374539	5.29E-06	4.39E-01
	Amaro Set	0.00446245	0.37484426	6.61E-06	3.79E-01
	Udra Body	0.0048101	0.29501555	4.30E-06	3.00E-01
PhoChOx (kg C_2H_4 eq/1 pc)	Aldan Set	0.00017139	0.00050725	1.93E-05	6.98E-04
	Amaro Set	0.0001588	0.00043837	1.68E-05	6.14E-04
	Udra Body	0.00017957	0.00034501	1.07E-05	5.35E-04
Acidi (kg SO_2 eq/1 pc)	Aldan Set	0.00354889	0.0049523	3.25E-05	8.53E-03
	Amaro Set	0.00334131	0.0042798	3.22E-05	7.65E-03
	Udra Body	0.00379982	0.00336835	2.86E-05	7.20E-03
Eutro (kg PO_4^{-3} eq/1 pc)	Aldan Set	0.00149172	0.00290165	0.00081624	5.21E-03
	Amaro Set	0.00138369	0.00250761	0.00070985	4.60E-03
	Udra Body	0.00139092	0.00197358	0.00044698	3.81E-03