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Environmental assessment of the rental business model: a case study for formal wear

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Abstract
The apparel industry and above all the business model on which it relies (fast fashion) are recognized as the source of marked environmental impacts. An alternative business model such as one of those promoted by the circular economy could be the solution to improve resource productivity and value creation, without damaging the environment. The rental model, or more in general the product-as-a-service, is often linked to multiple benefits such as reduction in environmental impact, increase in competitiveness and user value. However, to be sure of the environmental sustainability of this model, it is necessary to conduct an objective assessment of its application to the context of the apparel industry. The goal of this work was to carry out an analysis of the environmental impacts related to the life cycle of formal dresses. In detail, the analysis focused on the comparison between a business model based on rental of garments and an online purchase model. The results show that by extending the life of a product, in terms of the number of uses, it is possible to limit the environmental impacts associated with the fashion sector. In fact for the case under consideration, the rental business model makes it possible to extend the number of uses of a single dress, with a consequent reduction in the environmental impacts associated with its entire life cycle.

Keywords Rental business model · Life cycle assessment · Product-service system · Apparel industry

1 Introduction

Apparel consumption has increased dramatically during the last few decades. The current business model, the fast fashion, characterized by mass production, variety, agility and affordability, has been adopted by large international fashion retailers (Bukhari et al.,

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2018). The amount of clothes bought in the EU per person has increased by 40% in just a few decades, driven by a fall in prices and the increased speed with which fashion is delivered to consumers (Sajn, 2019). Based on the research published by the Think Tank of the European Parliament, clothing accounts for between 2 and 10% of the environmental impact of EU consumption but this impact is often felt in third countries, as most production takes place abroad (Sajn, 2019).

The production of raw materials, spinning them into fibers, weaving fabrics and dyeing require enormous amounts of water and chemicals, including pesticides for growing raw materials such as cotton (R Ananthashankar, 2013). Also, on the consumer use side, the environmental footprint due to the water, energy and chemicals used in washing, tumble drying and ironing is heavy (Muthu, 2015). As a very low part of used clothes are collected for reuse or recycling and less than 1% of material used to produce clothing is recycled into new clothing, representing a loss of more than USD 100 billion worth of materials each year (MacArthur, 2017), the need to address these issues is clear.

However, many actions need to be considered contemporary and circular economy can be regarded as an umbrella concept connecting different goals such as improving resource productivity and value creation, reducing value loss and destruction (Blomsma et al., 2018). Therefore, to support a systemic change in the fashion industry, a combination of new business models, innovative design, new technologies and materials is envisaged, and to be successfully implemented, circular economy transformation requires the design of innovative business models that can enable multiple value creation mechanisms (De Pádua Pieroni et al., 2018).

A list of circular business models (CBM) that change the usual way to run business in the fashion sector (Linder & Williander, 2017) could include: (a) rental or product-as-a-service (PSS): a one-off rental of a garment for a short time period; (b) subscription-rental: a monthly fee paid for access to a range of garments; (c) clothing resale: the recovery and resale of a garment by the original retailer or after a rental framework (e.g., consignment or peer-to-peer); (d) materials innovation (e.g., fibers from regenerative sources/by-products); (e) designing products in a way that would make reuse and recycling easier; (f) fiber-to-fiber recycling technologies; (g) clothing and textiles collection and sorting infrastructure; (h) digital enabling tech (e.g., tracking and tracing). It is also worth mentioning the relevance of new green and circular supply chain models that effectively take into account the topic of defective items, helping companies to find solutions for re-design their products and processes (Gautam et al., 2019).

Recognizing the value of utilization more than that of property, a performance-driven economy, where the consumer pays for the use of the product, could be successful (Mont, 2002). This is the reason of the analysis of the rental model carried out in this paper.

Some of the models mentioned above obviously cannot be considered novelties, such as the rental model. However, when this model leverages on new technologies, sharing platforms and the growing expertise on reverse logistics could be considered as a disruptive innovation (Christensen et al., 2018) and could represent a key aspect of a PSS strategy.

Rental service platforms lend products for a specified term (multiple days to several months, depending on the product category) or on a monthly subscription basis. “The rental service platform appeals to customers because it enables them to access items they otherwise could not afford” (Jin & Shin, 2020). In addition, those platforms offer many services connected to the choice of the garment, suggestions on the best outfits, multiple accessories coordinated and evaluations from previous customers.

Therefore, rental’s main key driver is the ability to offer a dedicated and unprecedented service: the opportunity for the customer to wear garments that previously were too costly.

This could be achieved both using a traditional store as a base or, preferably, through a digital platform that provides an online solution for the customer (B2C). The hired garment is usually paid one-off for a specific period and then it is sent back (Feng et al., 2020).

The rental model or more in general the PSS is highlighted as an important enabler for improved resource productivity and value creation, as well as for reduced value destruction (Stahel, 2010).

PSS application in industry is often linked to multiple benefits such as reduction in environmental impact, increase in competitiveness and user value (Mont, 2002). Compared to traditional business models around product sales, these are considered to be less resource-intensive because they allow manufacturers to meet the same demand with less products (Tukker, 2015). Besides the environmental benefits, economic and competitive benefits of PSS model range from the opportunity to establish longer and stronger relationships with customers, i.e., increasing customer fidelity, to the chance to open up new business opportunities, empowering strategic positioning (Vezzoli et al., 2018).

The definition of PSS is still not completely univocal, and in a recent study, we even found 52 different definitions of PSS and associated concepts identified from 47 of the most prominent papers in the PSS field (Haase et al., 2017). In use-oriented PSS, the focus is on providing functionality or access, for example, through leasing, renting or sharing instead of selling products (Gaiardelli et al., 2014). Even if most of the traditional empirical cases in the servitization are connected to business-to-business and manufacturing context, more and more examples come from consumer markets as textiles (Armstrong et al., 2015). Anyway, there is still a lack of methods/tools for experimenting, testing, and implementing the BM concepts (Pieroni et al., 2019).

This study aimed at exploring the environmental impacts associated with the application of a PSS strategy, and in more detail, the analysis examined the environmental burdens of a rental business model related to the clothing sector. The study was conducted using the life cycle assessment (LCA) methodology and was enriched by the comparison of the environmental impacts generated by the analyzed rental model and by a conventional purchase model (considered as a reference point). The case study, used for the analysis, refers to the clothing rental service offered by a small Italian company. The business model is based on the rental of formal (elegant and/or ceremony) dresses for women. This type of clothes plays an important role in the fashion world and often the phase of use of these garments is very limited in time—for various reasons like subjective perception, fashion, etc. The introduction of a rental business models can allow an extension of the lifespan of a cloth and therefore the development of more sustainable approaches also in the fashion world. The analysis of the environmental impacts with the LCA methodology has effectively allowed an objective assessment of the implementation of one of the main business models used toward the development of a circular and more sustainable economy.

2 Literature review

As previously reported, the world of clothing and fashion generates a significant amount of environmental impacts due to the high consumption of energy and water, greenhouse gas emissions, production of hazardous waste and discharge of toxic effluents into the water system (Nayak, 2020). In the literature, there are several works that have examined the impacts generated by this sector through the LCA methodology (Piontek & Müller, 2018) or that have tried, at a broader level, to deepen and investigate the concept of sustainability

applied to the world of fashion and textiles (Nayak, 2020). From many of these works, it emerges that environmental impacts are strongly conditioned by consumer behavior (Zamani et al., 2017) and by the geographical place, where the production and use phase of the garments takes place (Chapagain et al., 2006; De Saxcé et al., 2014; Kim et al., 2015). As indicated, both the production and use phases play an important role in generating environmental impacts. The environmental aspects linked to the production phase have always generated interest, and some works have tried to simultaneously analyze the economic and environmental effects of the quality of the products themselves; for example, recently, Khanna et al. (2020) tried to convey the effects of the production of imperfect quality items and the associated carbon emissions in a single mathematical model, with the aim of maximizing the profit function. The study underlines that to limit the possible growing costs of emissions, the best solution is to confine production only to the quantities necessary to obtain a profit. Zhao et al. (2021) in their work highlighted the importance of a careful environmental analysis of the raw materials used to make clothes. Analyzing the environmental effects of the use of different denim fabrics for the production of jeans, it emerged that a greater use of polyester-blend denim, compared to pure cotton, allows to reduce water consumption, but at the same time generates greater pressure on the reduction of carbon emissions. This result stems from the fact that the world production of fabrics is carried out almost exclusively in developing countries, which use energy resources linked to the massive exploitation of fossil fuels.

For a more exhaustive analysis, however, it is important to take into account the entire life cycle of the clothes, and a significant aspect in determining the overall environmental impacts is related to the number of uses and washes to which the clothes are subjected during their life cycle. In fact, these variables make the impacts associated more on the production phase (Steinberger et al., 2009) or on the use phase (Kim et al., 2015). Regarding the use phase, Farrant et al. (2010) noted that the possibility of reusing clothes would reduce the environmental impact of the clothing sector. Few works have still carried out an assessment of the environmental impacts associated with the development of real business models based on rental and PSS (Piontek & Müller, 2018). Zamani et al. (2017) have shown how the development of clothing libraries allows to reduce environmental impacts. In fact, the development of collaborative consumption business model, such as the clothes libraries, allows to extend the service lives of garments. This study also shows the importance of an efficient logistics service (transportation) in order to avoid rebound effects. To achieve environmental benefits, Piontek et al. (2020) highlighted the importance of the number of uses associated with a clothing rental model.

3 Materials and methods

The assessment of the environmental impacts, associated with the previously described business model, has been carried out using the life cycle assessment methodology. LCA is an environmental management tool that allows to quantify and evaluate the environmental impacts potentially caused by a process or a product. This analysis is conducted by collecting and quantifying the resources, the energy used and the emissions and waste associated with the entire life cycle of the product/process examined (Baumann & Tillman, 2004). SimaPro 9 software was used to model the entire system, and for the background data, it was used the Ecoinvent 3.6 database.

3.1 Goal and scope definition

The goal of this study was to assess the environmental impacts related to the garment rental service. More in detail, the analysis takes into consideration a specific category of garments, formal dresses, and compares the rental business model (called rental scenario) with an online purchase model (called baseline scenario). The analysis, from cradle to grave, examined all the impacts related to the entire life of the product system: from the production of the garments, use/reuse phase, up to final disposal.

The chosen functional unit was one average use of a formal (elegant) dress. The term "one use" refers to the use occurring within a 24-h time period that could be a specific occasion as a party, a ceremony or similar. What is meant is that the type of clothes considered are not suitable for use that can usually occur in everyday life.

For the rental scenario, the LCA analysis considered the entire life cycle of the garment starting from the production of the garment, then its distribution to the store (the Italian company that rents clothes), the use phase which consists of clothes packaging, round-trip transport to the customer and washing, up to the final disposal. Figure 1 shows a scheme with the life cycle phases took into account in the rental scenario (indicated by the blue boxes). Each phase is in turn divided into processes that allow a better characterization of the life cycle of a dress (black boxes). The arrows indicate the succession of processes along the life cycle; it should be noted that the use phase shows a cycle because it is assumed that the dress is used more than once, and therefore, it must be washed and repackaged before being used again.

The entire life cycle is also considered during the environmental assessment of the baseline scenario. The analyzed scenario is based on the more common model of online purchasing clothes: the dress is produced and subsequently sent to the buyer who uses it and then disposes of it; in this scenario, a return path of the product sold before its use has been introduced. Figure 2 shows the phases considered during LCA.

3.2 Inventory analysis

Since in this work the aim was not related to the assessment of the environmental impacts associated with the production of garments, it has been decided to focus more on the use phase part of the clothes' life cycle. For this reason, in all the scenarios considered, the production phase of a cloth was not modeled on the software by searching for primary or secondary inventory data, but the impacts relating to it were directly derived from the work of Sandin et al. (2019). The impacts related to the production phase have been adapted to represent a 450 g weight dress made entirely of cotton. As reported in the previous figures,

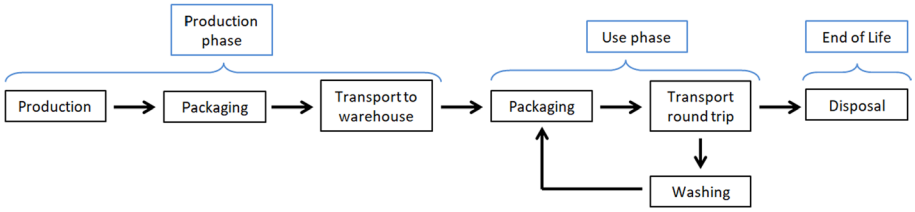

Fig. 1 Scheme of the life cycle phases (blue boxes) considered in the rental scenario; each phase was further divided into several steps (black boxes)

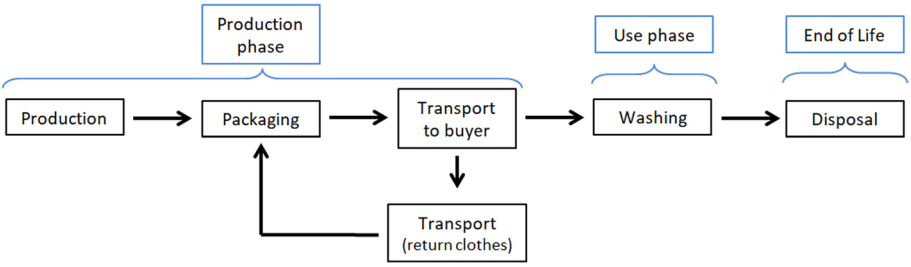

Fig. 2 Scheme of the life cycle phases (blue boxes) considered in the baseline scenario; each phase was further divided into several steps (black boxes)

in this phase the packaging of the manufactured garment and the transport were also considered. As regards the transport, in the case of the rental scenario, it was assumed as equivalent to the transport that takes place between the manufacturer and the warehouse of the rental company; on the other hand, in the case of the baseline scenario, the same value always represents the transport between producer and buyer.

All the data used to model the system are reported in Table 1;

The data to model the use phase for the rental scenario are primary data and have been obtained directly from an Italian company based in Milan; the service they offer and that has been modeled in this study involves women's clothes renting service. More in detail, the user can select the dress of interest online, and this is delivered directly to his home for the desired period of time (maximum four days); after use, the dress is returned to the company warehouse to be washed and arranged for subsequent rentals. The garments are sent to the users in a cardboard box (450 g) and wrapped in tissue paper (40 g). The phase of packaging disposal was also modeled, assuming that the paper was incinerated with energy and heat recovery—respectively 0.27 kWh of electricity and 1.95 of heat (Sandin et al., 2019). The data provided by the company show an average transport covered by the rental service of 40 km. (Although the service is extended nationwide, the main request is in the Milan area). In the rental scenario, the washing of clothes is commissioned to an external company located near the warehouse; the system was developed considering a transport of 3 km round-trip. All transport is assumed to be done by light commercial vehicles.

Concerning the washing step, two different alternatives were modeled: residential and dry cleaning. It has been assumed that in the baseline scenario people wash clothes directly at home, while in the rental scenario, the washing phase is entrusted to an external company. To obtain more reliable results, for the baseline scenario, it was decided to directly model the residential washing phase using the input–output data reported in the work of Sandin et al. (2019). The data used to model the dry cleaning phase were obtained from the laundry. Table 2 shows the inventory of the two considered washing option (data are reported for a single dress), while Table 3 reports the data related to the production of 1 kg of detergent.

Some clarifications need to be made regarding the washing phase:

- the option that in the baseline scenario clothes are washed in a laundry was not investigated;
- the electrical energy used to model the system refers to the Italian energy mix;
- the energy consumption related to the drying phase has been supposed assuming that only 19% of the clothes need this step (Sandin et al., 2019);

Table 1 Inventory of the analyzed system

Life cycle phase	Inventory data	Baseline scenario	Rental scenario
Production (1 dress)	Dress 100% cotton	See Sandin et al. (2019)	See Sandin et al. (2019)
	Cardboard—packaging	See Sandin et al. (2019)	See Sandin et al. (2019)
	Transport	See Sandin et al. (2019)	See Sandin et al. (2019)
Use phase (for a single use)	Residential washing	See Table 2	–
	Dry cleaning	–	See Table 2
	Cardboard—packaging (kg)	–	0.45
	Tissue paper—packaging (kg)	–	0.04
	Transport round-trip (kg*km)	–	36
	Transport (wash) (kg*km)	–	1.35
	Municipal waste collection—packaging (kg*km)	–	14.7
	Incineration—packaging (kg)	–	0.49
End-of-life (1 dress)	Municipal waste collection (kg*km)	13.5	13.5
	Incineration—packaging (kg)	0.45	0.45

Table 2 Inventory for the washing phase; all data refers to a single dress

Phase	Input	Amount	Unit
Residential washing			
Washing 40 °C	Tap water	2.79	kg
	Detergent (see Table 3)	0.00711	kg
	Electricity	0.101	kWh
	Wastewater treatment	0.00229	m^3
Drying	Electricity	0.057	kWh
Ironing	Electricity	0.081	kWh
Dry cleaning			
Dry cleaning	Tetrachloroethylene	0.00168	kg
	Electricity	0.2	kWh
Ironing	Electricity	0.081	kWh

Table 3 Inventory for the production of 1 kg of detergent

Input	Amount	Unit
Citric acid	0.0228	kg
Glycerine	0.0285	kg
Polyethylene, low density, granulate	0.0466	kg
Soap	0.0241	kg
Sodium hydroxide	0.0231	kg
Water, deionized	0.7022	kg
Polyethylene, high density, granulate	0.0466	kg
Polypropylene granulate	0.0101	kg
Printed paper	0.00126	kg
Fatty alcohol sulfate	0.1	kg
Ethoxylated alcohol	0.0591	kg
Electricity	0.25	kWh
Output	**Amount**	**Unit**
Detergent	1	kg

- the energy input for ironing was determined as if it took 6 min to iron a dress; however, compared to what reported by Sandin et al. (2019), it was assumed that only 50% of the dresses needs this step.

The end-of-life (EOL) stage of the garments was modeled according to Sandin et al. (2019); it is assumed that the clothes are collected by the municipal waste collection service and then incinerated. The heat and electricity recovered as a result of the process have been reported—0.25 kWh of electricity and 1.79 MJ of heat.

Based on the data collected over the years by the Italian company, on average, an item of clothing is used 7.5 times; this average value also takes into account the possibility that a garment will be irreparably damaged during its use (0.18%).

For the baseline scenario, it was assumed that a dress is used for a number of times equal to 3 (personal communication based on company interviews), subsequently it is kept

in the closet until disposal. The contribution of returned clothes was also included in the basic scenario since nowadays about 12.5% of the total clothing products sold are rejected by the buyer and returned to the seller (Appriss Retail's Report, 2019). To model this product return phase, 12.5% of the packaging and transportation value was added to the base production data.

3.3 Life cycle impact assessment

In the life cycle impact assessment phase, the large number of resources and emissions that form the inputs and outputs of the inventory are transformed into a handful of environmental impact categories. The considered impact assessment indicators are the IPCC 2013 GWP 100a method, cumulative energy demand (CED) and AWARE. According to Piontek and Müller (2018), these are the environmental impact categories that appear most frequently in the works that dealing with the themes of LCA in textiles sector and PSS.

More specifically, IPCC 2013 GWP 100a is a metric for estimating the relative global warming potential (GWP) due to atmospheric emission of greenhouse gas (GHG) over a time horizon of 100 years. The CED takes into account the gross energy requirement; the results are expressed in MJ and their calculation takes into account both non-renewable and renewable energy carriers, whose intrinsic value is determined by the quantity of energy taken from nature (Frischknecht et al., 2007). AWARE is the method used to assess the impact on water consumption and it is based on the publication of Boulay et al. (2018).

3.4 Sensitivity analysis

The life cycle analysis of the two scenarios—rental and baseline—was enriched by a sensitivity analysis. The goal is to evaluate the relative importance that the production and use phases of a dress, in the two scenarios, have on the final impact. The impacts obtained in the rental and baseline modeling—as previously described—were therefore considered as a reference point for this analysis. The impact of the entire life cycle of a garment was subsequently assessed by increasing and decreasing the environmental burdens generated by the production and use phases by 30%. The indicator examined was the global warming potential.

3.5 Scenario analysis

To deepen the evaluation associated with the two comparative scenarios, the effect of the transport distance for the rental service and the number of uses of a garment during its life was analyzed in more detail. The effect of the two variables was analyzed only against the global warming potential, thus calculating the kg of equivalent CO_2 emitted in the different circumstances.

To assess the effect of the transport distance, between the warehouse and the final client, the model of the rental scenario has been modified by assuming that beyond 100 km of transport the service would be carried out mixing different means of transport: light commercial vehicles, for a distance always equal to 40 km and heavy vehicles (7.5–16 ton lorry), for the remaining distance. This assumption is intended to represent an optimization of the logistics service, which, as indicated by Nayak (2020), is of primary importance toward an increase in sustainability of the fashion sector. It must be said that nowadays the

logistic optimization, both for economic but also for environmental reasons, is increasingly sought after by companies. By applying this form of transport and keeping all other model variables constant, the environmental impact was measured on the basis of the distance covered by the service. The baseline scenario was kept unchanged since, as noted above, the impact due to transport between the manufacturing industry and the end customer was assumed to be equal to the distance between the industry and the warehouse of the rental service, distances that have not been changed. Therefore, the impact generated in the baseline scenario is constant and independent of the distance.

Since the number of uses of a dress in the baseline scenario is based on an average value, it is interesting to assess the effect of changing this parameter on the overall environmental impact. The life cycle impact of a dress was estimated in relation to the number of uses of the dress during its life cycle. The model, for the baseline scenario, was made for value of 3, 5, 7 and infinite uses; instead in the case of the rental, it was modeled only for an infinite value of uses and for the number of times the dresses are used (7.5), according to the company information.

4 Results and discussion

In this section, the results obtained from the environmental assessment have been reported and discussed.

At first, the environmental impacts related to the previously identified functional unit (i.e., an average use of a formal dress) were analyzed. The following figures show the comparisons between the environmental impacts of the two different scenarios analyzed: the baseline scenario that refers to the classical retail and the rental scenario.

Figure 3 shows the kg of CO_2 eq. obtained for one average use of a dress in the two compared scenarios. As previously reported, it was assumed that in the baseline scenario during its life cycle, a dress is worn for a maximum of 3 times, while in the rental scenario, the number of uses of the clothes is extended to 7.5.

It is possible to observe how the rental scenario shows better environmental performance than the classic retail (baseline case). In both cases, the production phase (which

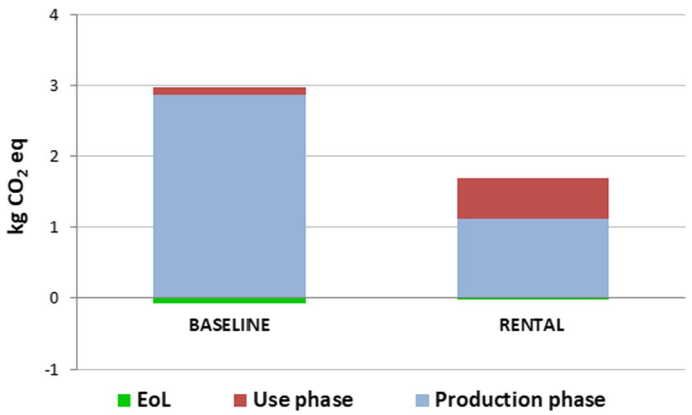

Fig. 3 Comparison of the global warming potential results for an average use of a dress in the two scenarios. The results are grouped for life cycle phases

includes the contributions of production, packaging and distribution) is responsible for the major environmental impacts. This result is due to the limited number of uses to which this class of clothing is subject. Although the impacts due to the use phase are greater in the rental case, the lower overall impact, in the latter case, is due to the sharing of the impacts of the production phase over a greater number of uses.

Table 4 shows the numerical values of the impacts calculated for the two scenarios, split up by individual contributions. The results, relative to the production and EOL phases, were normalized by the number of uses during the life cycle of the dress: 3 uses for the baseline scenario and 7.5 uses for the rental scenario.

Analyzing more in detail the results, reported in Table 4, related to the use phase of the rental scenario, emerges that around the 55% of the impact is caused by the packaging used during the service (cardboard and tissue paper); the 33% of the impact is due to the washing phase while only the 12% is related to the transport. For this impact category, the results relating to the washing phase show that dry cleaning causes about twice the CO_2 emissions compared to a residential wash with water; these emissions are mainly generated by the high energy consumption required by dry cleaning machines.

Table 4 Life cycle impact assessment results for one average use of a dress in the two considered scenario (baseline and rental)

Impact assessment indicator	Life cycle phase	Individual contribution	Baseline scenario	Rental scenario
IPCC 2013 GWP 100a (kg CO_2 eq)	Production phase	Production	2.283	0.913
		Confectioning	0.453	0.161
		Distribution	0.136	0.048
	Use phase	Packaging	–	0.308
		Transport	–	0.066
		Transport (wash)	–	0.002
		Washing	0.109	0.185
	EOL	Disposal	− 0.071	− 0.029
Cumulative Energy Demand (MJ)	Production phase	Production	41.717	16.687
		Confectioning	7.347	2.612
		Distribution	2.178	0.774
	Use phase	Packaging	–	8.730
		Transport	–	1.076
		Transport (wash)	–	0.040
		Washing	2.270	2.940
	EOL	Disposal	− 1.300	− 0.520
AWARE (m^3)	Production phase	Production	16.056	6.422
		Confectioning	0.042	0.015
		Distribution	0.015	0.005
	Use phase	Packaging	–	0.152
		Transport	–	$4.2*10^{-04}$
		Transport (wash)	–	$1.7*10^{-04}$
		Washing	0.043	0.096
	EOL	Disposal	− 0.019	− 0.008

The impacts related to the end-of-life phase assume negative values in both scenarios; this is because it has been assumed that the clothes are sent to an incineration plant with consequent recovery of heat and electricity that go to feed the national energy mix.

The results obtained with the cumulative energy demand method, comparing the average use of a dress in the two scenarios, are shown in Fig. 4.

Also in this case, the rental scenario shows minor impacts compared to the base case; the production phase is always responsible for the heaviest impacts.

Similarly to what was observed in the previous case, the impact of the use phase is made up of 68% by packaging, 23% by washing and only 8% by transport.

There is a difference between the basic scenario and the rental as regards the impacts related to washing: residential washing requires 2.27 kWh per single wash, while dry cleaning requires 2.94 kWh.

Also, in this case, the impacts related to EoL phase are negative.

The assessment of the water consumption impact, sensitive category when it comes to cotton clothes and processes that require a washing phase, is shown in Fig. 5.

In this case, it can be seen that almost all the environmental impact is attributable to the production phase; in fact, both during the cultivation phase and in the subsequent processing, cotton requires a considerable amount of water (Muthu, 2015; Zhao et al., 2021). Analyzing the use phase (Table 4), it emerges that the impact of the rental scenario is higher than the baseline case: 2.48 m^3 vs 0.04 m^3; the greatest contribution of the use phase of the rental service derives from the packaging of the clothes at each use (around 61% of the total impact of the use phase).

4.1 Sensitivity analysis

Figure 6 shows the overall variations on the IPCC 2013 GWP 100a indicator when the impacts relating to the production and use phases of the garments are modified by ± 30%. (This variation was applied both for the rental scenario and for the baseline scenario.)

As shown in Fig. 6, it can be seen that the variation of impact has a greater effect if applied to the production phase of the dress, both in the direction of the increase in impacts (prod + 30%) and in that of decrease (prod -30%). A ± 30% change in impact

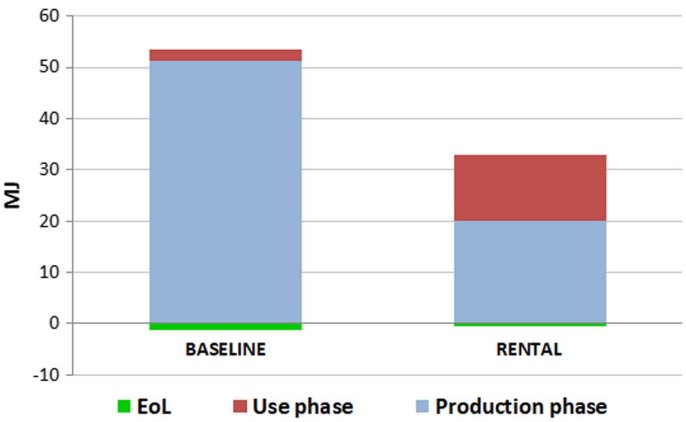

Fig. 4 Comparison of the CED results for an average use of a dress in the two scenarios. The results are grouped for life cycle phases

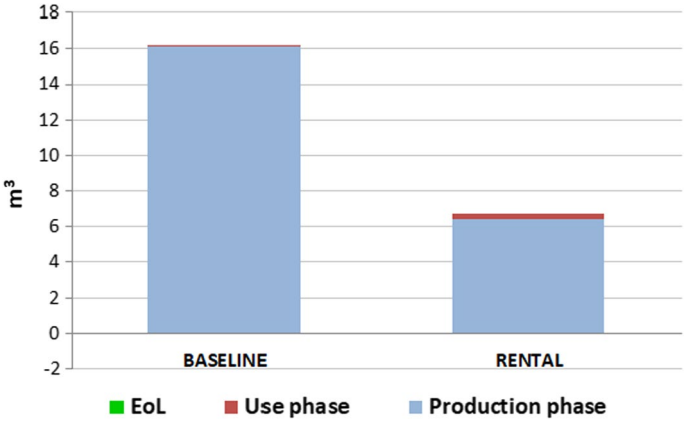

Fig. 5 Comparison of the AWARE results for an average use of a dress in the two scenarios. The results are grouped for life cycle phases

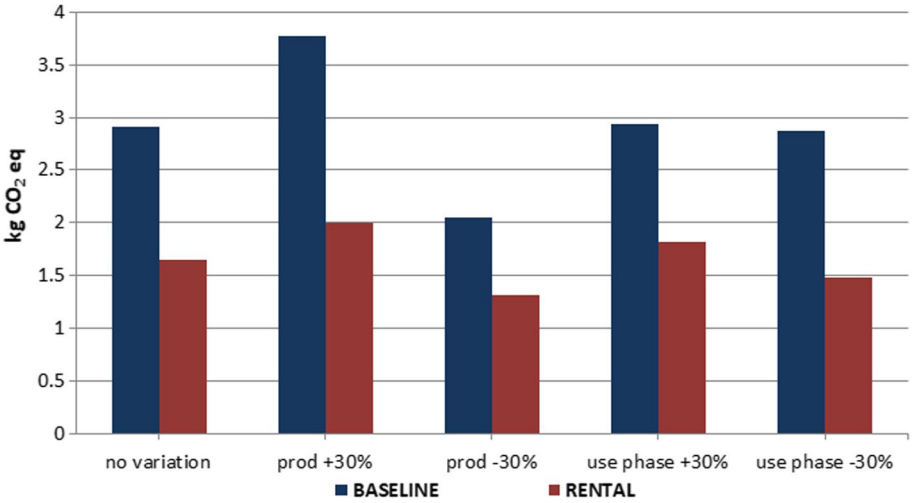

Fig. 6 Variations on the IPCC 2013 GWP indicator when the impacts relating to the production and use phases of the garments are modified by ± 30%. The two dashed lines are used to facilitate the comparison with the impacts obtained without variations

applied to the production phase, in the baseline scenario, involves a variation in the final impact of ± 29.6%, respectively; this result is achieved because in this scenario, the production phase of a dress is responsible for the greatest impacts along the entire life cycle. The variation in the overall impact, in the rental scenario, is instead equal to ± 20.4%. It can be noted that in both cases the change in impact on the production phase strongly affects the final impact.

On the other hand, variations with respect to the use phase have little effect on the final result. A change in the impact on the use phase, in the baseline scenario, results in a change in the final impact of only ± 1.1%. On the other hand, the change in the overall impact, in the rental scenario, is equal to ± 10.2%. In this case, it can be seen that the

impact variation in the rental scenario influences the final result more than the baseline scenario; in fact, as already highlighted in Fig. 3, this effect is due to the greater environmental burden of the use phase that this scenario entails. However, since the rental scenario allows for a greater number of uses of a dress, the overall impact, expressed as kg CO_2 eq., is still lower than that of the baseline scenario.

This analysis allows to highlight how the production phase, together with the number of uses of a dress, remain the main variables on which it is necessary to operate in order to reduce the environmental impacts associated with the world of fashion.

4.2 Scenario analysis—transport distance

Figure 7 shows the trend of the environmental impact with respect to the distance that the rental service must cover. As a reference point, the kg CO_2 eq. released by the baseline scenario are reported (red line); as this scenario is not affected by the effect of distance, the impact is represented by a horizontal line (constant value with increasing km).

The impact associated with the rental scenario is directly proportional with the increasing distance, but it can be noted how the slope of the curve is very flattened, especially after the distance equal to 100 km (where the transport was modeled with larger vehicles). Even if the clothes are transported with light commercial vehicles, a breakeven point between the impacts of the two scenarios would be achieved only for distances close to 1000 km. Obviously, this result is valid only if the rental service, through the company who takes care of the transport, manages to keep the optimization of the loads constant. From these results, it emerges that the impact due to the transport of the garment is really limited and has little effect on the final result. However, this result is strongly conditioned by the number of uses of the dress during its life cycle. In the baseline scenario, the overall impact associated with the life cycle of a garment depends on the number of uses it undergoes; in fact, if the number of uses increases (in this case it exceeds the value of 3), the impacts related to production and end-of-life decrease. Thus, a situation can be reached in which the straight line of impacts caused by the baseline model approaches the line of the

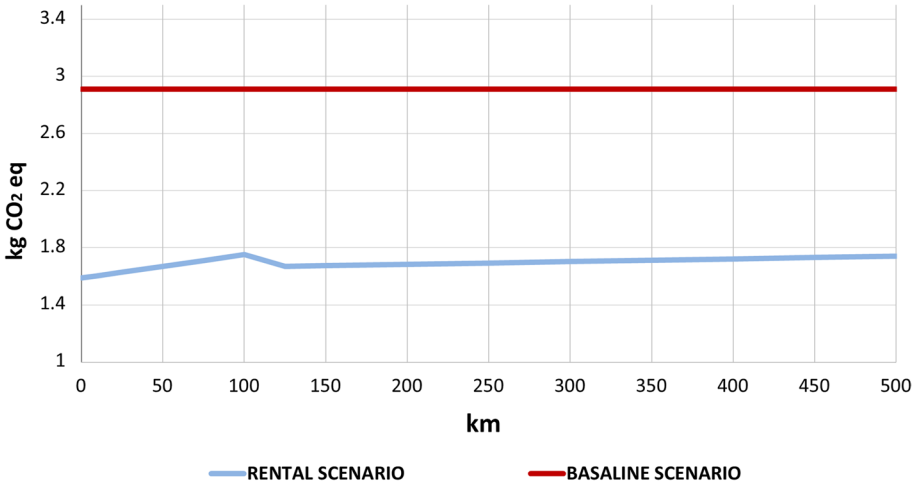

Fig. 7 Effect of the transport distance on the overall impacts for the two scenarios

rental scenario or even positions itself below—in this case, it will be the classic clothing purchase model that will generate the least environmental impacts.

4.3 Scenario analysis—number of uses of dresses during their life cycle

The effect of the number of reuses of a garment on the overall impact was modeled, and the results, relative to the global warming potential, are shown in Fig. 8. The *X* axis reports the possible number of uses, while the axis *Y* shows the corresponding environmental impact. The comparison has been made between the rental scenario (blue lines) and the baseline scenario (orange lines).

The two solid lines show the trend of the environmental impact (kg CO_2 eq), in the two scenarios, using a single dress for a number of uses > 12. It is immediately evident that the environmental impact associated with the rental service is greater than in the classic baseline case; this result is due to the greater impacts linked to the use phase of the rental model, already observed previously (Figs. 3, 4). However, when the modeling is made more realistically, assuming a precise and limited number of uses, a clear change in the trend of the impact is observed. In fact, the baseline scenario modeled assuming only a maximum of three uses of a dress during its lifespan leads to a considerable increase in the environmental impact.

The difference between the two scenarios narrows as the number of uses of the single dress, for the baseline case, increases; when this value reaches 7 uses (dotted line), the environmental performances associated with the baseline scenario were found to be better than those of the rental scenario. It should be noted that in the rental scenario, the average use of each garment for a number of times equal to 7.5 is a reliable and real value. On the other hand, in the classic case of the purchase of a dress, the number of real uses can be

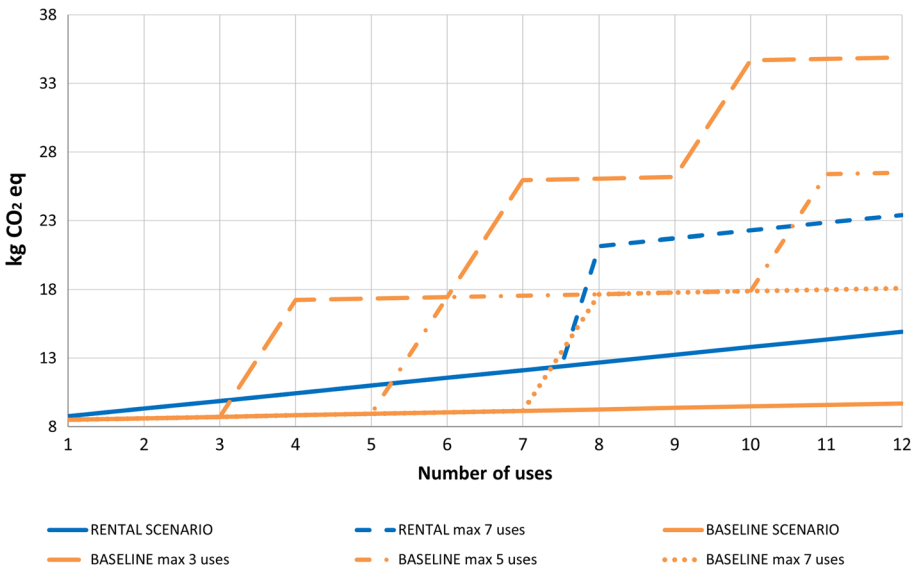

Fig. 8 Effect on the environmental impact of the number of uses of a dress during its life cycle

very limited for various reasons (fashion, preferences, needs, social conditioning, etc.), and it is difficult to reach the same number of uses as the rental scenario.

Some clarifications must be made regarding the study and the results:

- The modeling of the two scenarios regarding the production phase is simple and is not based on primary data; the same impacts have been attributed to the two scenarios, but it should be noted that the company offering the rental service reserves the right to use clothes that have been manufactured trying to limit the environmental impacts and with a sustainable supply chain. In fact, as shown in the work of Zhao et al. (2021), the focus on effective and efficient production, using renewable energies, must be a priority if the garment industry is to be made more sustainable and a greater attention to these aspects should certainly favor the rental scenario from an environmental point of view;
- In the modeling of the return of clothes in the baseline scenario, a very sensitive aspect has been left out: in fact, often the returned clothes are directly disposed of without re-entering the market; this aspect for lack of objective justifications has not been modeled in the system;
- For a better evaluation of the differences between the two possible washing systems, an in-depth study is required; in fact, it would be appropriate to compare the two washing methods by expanding the number of impact categories considered, since some of these could be more affected by the use of tetrachloroethylene. There are other washing technologies that have been gaining ground in recent years (supercritical CO_2, professional wet cleaning, etc.) and that could prove to be environmentally advantageous over tetrachlorethylene.
- In both scenarios, the modeling of a possible second or more life of the clothes (resold, given away, given in charity, etc.) was omitted, as it would have complicated the system; it should be emphasized that some dresses, used in the rental scenario, once the period of use is over, return to the manufacturer so that he can dispose and recover the fabrics present in them;
- The quality aspect of the dresses themselves has been deliberately omitted as it is linked to subjective perceptions.

5 Conclusions

This study, through the LCA methodology, has allowed to determine how the business model based on the rental of formal dresses enables to reduce the environmental impacts associated with this sector. This result is achieved thanks to the approach inherent in the rental model which effectively allows to extend the lifespan of the product; in fact, formal dresses are often used for a very limited number of times. The work investigated the environmental impacts generated along the entire life cycle of a formal dress, comparing a classic purchase scenario with a rental one. From the results emerge how the rental scenario shows limited environmental impacts, for all the impact categories considered: Global Warming, Cumulative Energy Demand and water consumption. While the impacts related to the use phase (packaging, transport, etc.) show a moderate growth, the possibility of extending the number of uses of the clothes, connected to the PSS model, allows to reduce the heavy impacts related to the production phase. This analysis showed that during the use phase, in the rental scenario, packaging plays a particularly influential role in generating environmental impacts. In fact, for the global warming and cumulative energy demand

categories, the packaging is responsible, respectively, for 55% and 68% of the impacts generated by the use phase of the clothes. Trying to limit the use of packaging or being able to reuse it could further improve the impact generated by clothing rental.

Conversely, the transport of garments in the rental scenario does not cause such high impacts. This result derives from a modeling that assumes that transport is always optimized: in terms of load and type of vehicle used.

The impacts caused by dry cleaning are approximately double those generated by a residential wash; impacts caused mainly by the high energy consumption of the dry cleaning machinery. The possibility of changing the type of washing used with a more environmentally sustainable solutions could be of further benefit.

The economic issue is primary when it comes to business models and that is why as a future perspective, it would be very useful to carry out an economic analysis relating to the life cycle of the rental model; since this business model can be considered appropriate only if, from an economic point of view, an effective profit is obtained from the rental of the clothes. In addition to an economic analysis, it would also be advisable to conduct research to evaluate the real level of inclination of people toward similar business models, which require a different approach to products by both buyers and sellers.

Finally, it is right to specify that the analysis addressed in this study refers to a specific and very restricted context. The results obtained are difficult to translate to different business models, for example where the rental takes place for everyday clothes. However, the overall result of the analysis could incentivize a niche market, such as that of fashion, to explore new business models with a view to greater environmental sustainability.

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Availability of data and materials The authors declare that the data supporting the findings of this study are available within the article.

Code availability Not applicable.

Declarations

Conflict of interest The authors have no conflict of interest to declare that are relevant to the content of this article.

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