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'A blockchain-enhanced Product Stewardship framework for the fashion value chain'

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Abstract

Even though the fashion industry environmental and social impacts may be commonly underestimated, the significance of the sector for the achievement of 2030 Sustainable Development Goals results crucial. Apparel production processes and use phase habits entail indeed disproportionately large consequences in relation to widespread increases in pollution levels and solid waste creation. The situation displays an even worse future perspective in relation to the enhancements in disposability of clothes, the expansion in global population and middle classes especially in developing countries, as well as the rising level of globalisation of flows complicating the supply network. In these circumstances, the loss of transparency and the worsening of sustainability performances is inevitable. Additionally, the increase in virgin raw material prices and in possible supply chain risks, undermines the long term economic performances and persistence of apparel sector businesses.

It is therefore critical to act on the longevity, reusability and recyclability of garments, as well as on the reduction of polluting impacts along all stages of the life cycle. Consistently, circular economy principles, excess management regulations and digital technologies implementation provide the potential for the resolution of diverse current state issues. Still the true differentiating factor may arise from the integration of the strength points of these three innovative conceptions. This dissertation thus investigates the multifarious insights recoverable from the current state of the art and practice, in addition to more concrete and thorough inputs gained through specialised interviews with industrial pioneers for the sustainable development of the textile industry. Accordingly, the research work aims at developing a comprehensive framework for the exploitation of the synergies among circular fashion business models, product stewardship schemes and blockchain architecture. The specific focus will regard the individualisation of subsidies, fees and discounts, for the sake of a higher effectiveness in incentives outcomes, adapting to the requirement of each supply stage. On the other hand, blockchain technology works as the authentic enables of the features evolved in the framework, given its fundamental role in providing advanced traceability of flows and payments, security, efficiency, support for certification process as well as for end-to-end customer engagement.

Finally, the design of the model is validated through a two-fold evaluation procedure, considering both the financial outcomes for each value chain actor and a connected Life Cycle Assessment analysis, for a specific product investigated. In these regards, both tests provide proof of the robustness and significance of the framework for the resolution of fashion industry current state issues.

Sommario

Nonostante possano essere generalmente sottovalutati gli impatti ambientali e sociali dell'industria della moda, l'importanza di tale settore risulta cruciale per il raggiungimento dei Sustainable Development Goals per il 2030. I processi di produzione e le abitudini per la fase d'uso relativi all'abbigliamento comportano difatti conseguenze sproporzionatamente gravi in riferimento all'aumento globale dei livelli di inquinamento e dei volumi di rifiuti tessili. Inoltre, queste condizioni sotto intendono una prospettiva futura anche peggiore, a causa della riduzione progressiva dei cicli di vita dei prodotti di moda, l'espansione della popolazione mondiale e della classe media specialmente nei paesi in via di sviluppo, così come l'incremento nei livelli di globalizzazione dei flussi di materiali, complicando ancor di più la rete distributiva. In questi termini, la perdita di trasparenza e il peggioramento nelle prestazioni di sostenibilità è inevitabile. Oltre ciò l'inflazione nei prezzi di materie prime vergini e l'acuita possibilità di shock infra-filiera minano le performance economiche di lungo termine e la persistenza futura di aziende del settore tessile.

Per questo, è necessario agire sulla longevità, riutilizzabilità e riciclabilità degli indumenti, in aggiunta all'attenuazione degli impatti inquinanti attraverso tutte le diverse fasi della filiera tessile. Di conseguenza, sia principi di economia circolare, sia normative per la gestione dei rifiuti, sia l'implementazione di tecnologie digitale includono il potenziale di risoluzione delle attuali molteplici problematiche dell'industria della moda, per cui il fattore di differenziazione nasce dall'integrazione dei punti di forza di queste tre concezioni innovative. Questa dissertazione si basa quindi sull'approfondimento di svariate considerazioni raccolte dall'analisi della letteratura scientifica e reportistica, oltre a riflessioni più concrete e accurate ottenute attraverso interviste specializzate con aziende pioniere dello sviluppo sostenibile del settore tessile. Perciò, il lavoro di ricerca mira a sviluppare un modello teorico per lo sfruttamento delle sinergie presenti fra business model di moda circolare, schemi di responsabilità estesa e architettura blockchain. Inoltre il focus riguarda l'individualizzazione di sussidi, quote e sconti, con l'obiettivo di massimizzare l'efficacia dell'applicazione di tali incentivi, adattandosi quindi alle esigenze di ogni fase della filiera. D'altra parte, la tecnologia blockchain opera in questo contento come autentico abilitatore dei diversi tratti sviluppati nel modello, dato il ruolo fondamentale nel garantire tracciabilità avanzata di flussi di materiali e pagamenti, sicurezza, efficienza, supporto ai processi di certificazione e ad un servizio continuo e completo al cliente.

Infine, la struttura del modello viene convalidata attraverso una doppia procedura di valutazione, considerando sia esiti finanziari per ogni attore della filiera sia esiti dell'analisi del ciclo di vita dello specifico prodotto investigato. Entrambi i test forniscono prova della robustezza e rilevanza del modello.

EXECUTIVE SUMMARY

This dissertation is built aiming at the provision of factual, technological and managerial rationales in support of the resolution of fashion industry current state detrimental impacts, responding to the needs of tomorrow with a brainstorm of today's edgy innovations. Accordingly, this chapter represents a brief excursus of the whole research evolution, clarifying the process of evolution of the novel framework proposed, rooting from the findings related to the state of the art and practices, as well as on-field industrial insights.

Research Objectives

The comprehensive designated objective of the dissertation is to: *Establish a link between regulative policies and technologies exploitation, in order to develop a framework characterised by well-aimed adaptation to the business context, concrete implementation potential, incentives effectiveness and ability to drive widespread balanced consequences throughout the whole fashion value chain.*

In particular, the development of the work follows the investigation of the following research questions:

***RQ1*. What are the causes for a fashion industry state in which it is now plenty of circular business model tools but there is still no wide diffusion of strategic circular approaches?**

***RQ2*. What possible scenarios of consumption and production patterns will be enabled in the near future by the upcoming technologies?**

***RQ3*. How would it be possible to effectively incentivize companies towards closed-loop developments?**

Scope Overview

The boundaries of the analysis entail the whole fashion apparel supply chain, focusing on textile fibre inputs for garments' manufacturing, within a European geographical horizon. This choice was driven by the forecasted potential effectiveness of textile-to-textile recycling for the fashion sector when put in connection with the upcoming innovative chemical reprocessing technologies. The spatial boundaries, on the other side, reflect a particular regulative framework as the one of the European Union, with a keen orientation towards continuous improvement in sustainability performances both for process and industrial structures.

Furthermore, the fashion segment covers the major fraction of the textile industry market and owns also the major weight and responsibilities for environmental degradation and human rights over-exploitation, thus resulting in an extremely significant scope on which to work further (Fashion for Good and Boston Consulting Group, 2020). Generally, as stated by the Global Fashion Agenda and the Boston Consulting Group (Lehmann *et al.*, 2018), the Pulse Score[1], a health measure for the fashion industry, was 38 out of 100 in 2018, showing great hidden costs and great margins for improvement. Consequently, since the fashion industry attained also second place among the most polluting industries (Quantis, 2018), wide interest is driven in these years towards these issues. According to the Pulse of the fashion industry report, the most promising action areas are: Sustainable Materials Mix, Closing the Loop, and Industry 4.0 (Lehmann *et al.*, 2018), which are exactly the fundamental concepts on which this dissertation is evolved.

Methodology

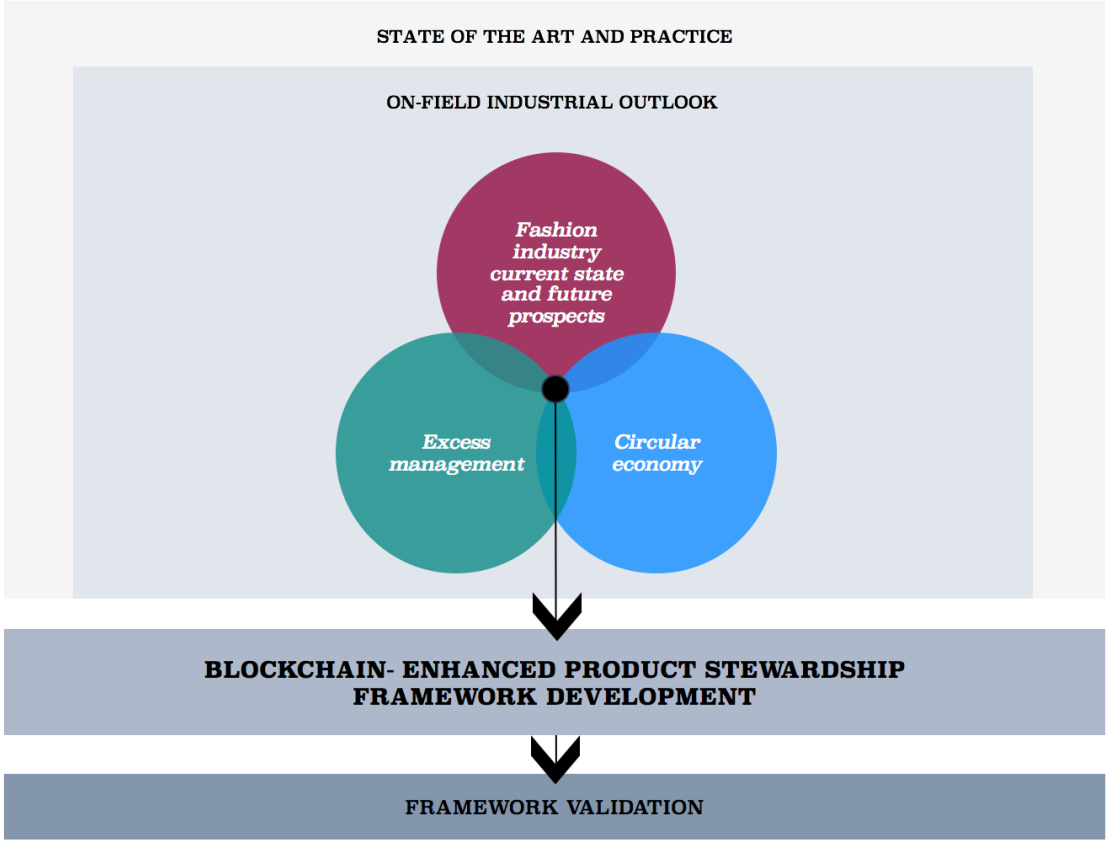


Figure ES. 1 - Framework development diagram

[1] The Pulse Score is a global and holistic baseline of the sustainability performance in the fashion sector. It is based on the Sustainable Apparel Coalition's proprietary Higg Index and extends its scope to extrapolate its findings to the entire industry.

Aiming at the thorough evaluation of all the possible beneficial modelling features applicable to the fashion supply chain structures, the review of the state of art combines scientific literature and grey literature in an integral way. In order to be able to propose truly constructive propositions it was necessary to dig into a great variety of topics, i.e. different branches of fashion environmental issues, challenges, business models; circular economy models, drivers and barriers; excess management paradigms, current limitations and future potential solutions.

Furthermore, as shown in Figure ES.1 a crucial step was the deepening and expansion of insights gathered from the literature review with on-field industrial outlooks, gathered through 16 interviews with relevant fashion industry players. The chosen sample entails a heterogeneous combination of more or less 'sustainability champions', made up of both incumbents and various start-ups, thus offering a great variety of forehand data about innovation frontiers, operational hurdles and strategic directions. As a matter of fact, this primary information set was critical for the evaluation of potential solutions, assessing their operational feasibility, adjusting the features of the model according to diversified requirements of each supply chain stage and finally providing a qualitative validation of the framework.

Summing up, the model development process was characterized by massive reiteration and re-evaluation of features as well as of their combination's significance and support towards the desired objectives, both basing on the state of art and practice as well as on industrial interviews. In particular, the framework roots in the integration and exploitation of synergies among the three research areas of fashion unsustainability issues, circular economy business models, including digital, NIR sorting and chemical recycling technologies, and finally excess management paradigms, where extended producer responsibility represents the major reference for the model.

For what regards the concrete quantitative validation of the framework, aiming at an alignment with the investigated logic of an indirect impact relation between economic convenience of circular investments and overall sustainability improvement, the framework testing ground is structured in two interconnected economic and environmental performances sub-tests. The two-fold assessment bases on a case study built by merging different single firm cases, practically setting up a hypothetical supply chain for a specific product. This integration exercise ex-ante shall afterwards enable a proper evaluation of both single actors as also of integrated value chain effects, explicating the depth of interrelations to consider when designing an incentive regulation. Furthermore, both validation analysis will be applied to multiple scenarios for each supply chain actor, comparing the business-as-usual case with other three different cases of gradual implementation of the diverse features proposed in the model. The heterogeneity entailed favours indeed different company behaviours, with rising preference in accordance with the waste hierarchy.

In the ***'Financial Sustainability Test'*** the objective is to demonstrate the negative profitability trend present for Business-As-Usual scenarios and to provide support for the long term business persistence achievable through circular investments encompassed in a diversified product stewardship regulative framework. The expectation to verify refers to the fact that profitability enhancing factors shall exceed additional costs to bear for sustainability-oriented companies. Accordingly, the algorithm used to allocate product stewardship contributions and to achieve the desired objectives is the following:

1. *Cover operating costs for end-of-life management (assuming that everything that is produced is destined to pre- and post-consumer waste)*
2. *Define resulting figures net of revenues*
3. *Distribute fees weighting according to firm's waste volumes and supply chain position impacts*
4. *Define discounts for producers according to impacts (volumes) avoided from EOL common management*
5. *Define subsidies in order for EOL actors to have a positive breakeven*
6. *Assess delta NPV of circular investments vs Business-As-Usual for each actor (at different levels of application of the model)*
7. *Assess supply chain effects*

For what regards the ***'Environmental Sustainability Test'***, especially for the fashion ecosystem, there is a critical prerequisite to develop and exploit more accurate and standardised methods for the evaluation of polluting impacts diversity and for proper comparisons among various sourcing, production and disposal alternatives. The methodological choice thus consists of a Life Cycle Assessment through the use of the software Simapro. The aim is to define the most impacting supply chain areas and inputs as well as to assess the effects over the following manifold impact categories, thus avoiding inaccuracies present in single impact assessments: 'Climate change Human Heath', 'Ozone depletion', 'Human toxicity', 'Photochemical oxidant formation', 'Particulate matter formation', 'Ionising radiation', 'Climate change Ecosystems', 'Terrestrial acidification', 'Freshwater eutrophication', 'Terrestrial ecotoxicity', 'Freshwater ecotoxicity', 'Marine ecotoxicity', 'Agricultural land occupation', 'Urban land occupation', 'Natural land transformation', 'Metal depletion', 'Fossil depletion'.

Both tests are based on various estimates and assumptions. Absolute values of results may be thus deviated but do still lead to reasonable findings from a qualitative point of view, considering the delta of performances' improvement, used to analyse the preference over alternative strategies.

State of the Art and Practice

According to the author's knowledge, current literature provides extensive analysis of single models and single topics but lacks of a more comprehensive integrative perspective. Particularly, the state of the art and practice conclusions point out the urgency to act on fashion supply chains' leanness, flexibility, social and environmental sustainability, as well as lack of traceability.

Within the 'Fast Fashion' revolution (Lowson, King and Hunter, 1999), indeed, alongside with *time to market, delivery time, offer variety and ceaseless novelty*, *cost* generally strengthened its role as parameter driving the rising competition. According to enhanced relative convenience of clothing within the average consumption basket (European Parliament, 2019), consumers began considering clothing, shoes and accessories as disposable goods (as shown also in figure ES.2), following the economic imperative of "Spend now, think later", buying without reasoning and dramatically lowering the rates of clothing utilization by 36% in 15 years (Foundation, 2017).

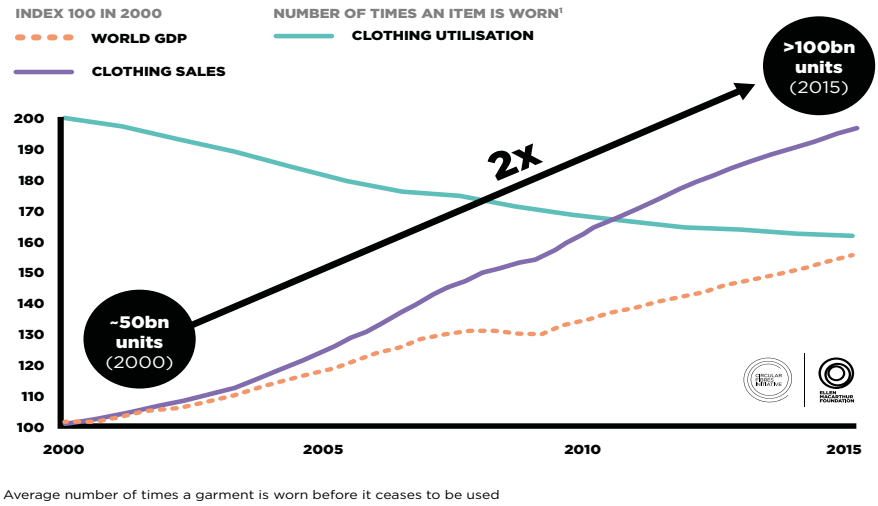


Figure ES. 2 - Growth of clothing sales and decline in clothing utilisation since 2000 (Foundation, 2017)

These macroeconomic impacts on consumption and production patterns are followed by a critical loss of transparency and detrimental expansion in pollution effects and waste creation. The Pulse report computes a total of 3990 million metric tons CO_2 eq emissions in 2016, posing the apparel and footwear industry impacts at 8,1% of the global cross-sector estimation (Lehmann et al., 2018). On the other hand, the Ellen MacArthur Foundation estimated 92 million tons of textile waste created annually from the fashion industry, namely the equivalent of one garbage truck of textiles landfilled or burned every second (Foundation, 2017). Furthermore, this environmental unsustainability is linked also to a diminished economic long-term sustainability of businesses.

Projections point out that, by 2030, fashion brands would see a decline in earnings before interest and tax (EBIT) margins of more than three percentage points, if they were to continue business as usual. This would translate into a profit reduction of approximately EUR 45 billion (USD 52 billion) for the industry (Lehmann et al., 2018).

However, the recent Pulse of the fashion industry report also estimated that the overall benefit to the world economy could be about EUR 160 billion (USD 192 billion) in 2030 if the fashion industry were to address the environmental and societal fallout of the current status quo (Lehmann et al., 2018). The merging of these factors therefore causes significant interest across industry stakeholders to find appropriate solutions for value recovery and enhancement.

Consistently, the Global Fashion Agenda set 213 targets in July 2019 referring to 4 main action points (Global Fashion Agenda, 2019):

- *Implementing design strategies for cyclability (41% of total targets)*
- *Increasing the volume of used garments and/or footwear collected (24% of total targets)*
- *Increasing the volume of used garments and/or footwear resold (13% of total targets)*
- *Increasing the share of garments and/or footwear made from recycled post-consumer textile fibres (22% of total targets)*

This incentivises the following of the waste hierarchy and the development of innovative business models for eco-design, rental, resale, re-commerce and generally the shift from an economy based on the sale of goods to one based on the sale of performance (Webster *et al.*, 2014).

Accordingly, it is necessary to develop a system in order to exploit circularity supporting technologies once they will be at scale. The fashion industry, in particular, will require the full exploitation of RFID, genetic markers and sorting technologies in order to truly implement closed loop, preparing the garments for reuse or recycling (Lehmann et al., 2018). Hence, in addition to the enabling digital technologies, a key success factor of the circular revolution initiative will be the effectual usage of the information that can be recovered and shared. In respect to this, blockchain technology represents the missing element necessary to not only enhance the full adoption of circular business models but also provide confidence and security to the supply chain. It seems that inefficient transactions, fraud, pilferage, and poorly performing supply chains, lead to greater trust shortage, and therefore, a need for better information sharing, and verifiability (Saberi et al., 2019). This digital layer shall indeed grant advanced transparency on financial and material flows, as well as end-to-end customer engagement and facilitated certification processes,

in order to provide a form of signalling for the revolution of industry production, consumption and disposal patterns (Reverse Resources, 2017).

Furthermore, if businesses and policymakers will be able to effectively cooperate and carry out step-by-step improvement programs, it will be actually possible to fully capitalize on the higher value in circulation and assure a more sustainable future (Reverse Resources, 2017). Against the current obscure ecosystem, there are indeed innovative solutions on the way under development in these present years. Automation of sorting and discovering of new technologies for textiles recycling, e.g. chemical recycling, have been given more attention recently and developed systems are expected to shine in the near future (Girn *et al.*, 2019). These chemical recycling technologies promise much higher performances in output quality, system effectiveness and environmental sustainability, being able to fulfil the present great improvement margins, linked to the low closed-loop recycling rates. However, in order to reach effectiveness in reuse and recycling, the collection and sorting infrastructure shall be scaled up and optimised. It will be thus necessary to act with top-down incentive approach in order to manage these collective action hurdles (Genovese *et al.*, 2017).

Regarding excess management, important considerations can be gathered from different theories. The crucial principle of industrial symbiosis networks, for instance, it to create the basis for win-win conditions (Albino, Fraccascia and Giannoccaro, 2016). Further on, reverse logistics embody the logistical outlook in order to empower concretely closed-loop business models. In particular, RL implementation and management is commonly dependent (Govindan and Bouzon, 2018):

- *on the support and participation of the key stakeholders;*
- *on the shared responsibility through the reverse SC to bring back EOL products;*
- *on the resources committed to RL operations.*

It shall thus be beneficial to support the optimisation of reverse logistics through a framework facilitating the sharing responsibilities, costs and benefits and which enhances the collaboration among supply chain stakeholders. In respect to this, the model of Extended Producer Responsibility may encourage a change in behaviour of all actors involved in the product value chain: product-makers, retailers, consumers-citizens, local authorities, public and private waste management operators, recyclers and social economy actors. (Oecd / European, 2014). The provision of a system focused on extended producer liability appears to be the logical transposition of not only the polluter pays principle but also the principles underlying the waste hierarchy and is therefore considered a key tool in the promotion of the circular economy (Jacometti, 2019). Following the PPP approach, responsibility should be shared along the entire supply chain (Lenzen et al., 2007). Still, in the design phase of

the regulation, policy makers shall regard the persistence of the following possible systematic failures (Oecd / European, 2014):

- *Imprecise responsibilities and insufficient formal dialogue among stakeholders*
- *Producers' fees seldom reflect the true management costs (coverage issues)*
- *Fair competition should be ensured*
- *Insufficient transparency and need for surveillance*

In connection to this, various potential solutions are identified. First of all, the fee should be established per product: this way the fee can be linked directly to the cost of collection and disposal of the product when it becomes waste, which simplifies communication to the market and households (Oecd / European, 2014). The exploration of technological solutions (block-chain and smart contracts for example) to automate EPR processes and payments was also proposed. Goods could be "linked" with their digital counterpart through unique identifier codes registering any EPR payment. Furthermore, block chain technologies also intrinsically support the monitoring and tracing of the textiles flow, while driving the accomplishment of the objectives of subsidies enabling recycling organisations to: improve their performance; increase their sorting capacity; and improve the sorting and recycling performance (Bukhari, Carrasco-Gallego and Ponce-Cueto, 2018).

Industrial Insights Analysis

Interviewees mainly confirm literature propositions and highlight the future opportunities and the potential strategies, against current costs and inefficiencies present for closed-loop systems.

In order to determine the development stage of the industry, Circle Economy elucidates: "*We can observe from the past years that more and more companies are starting to focus either on sustainability or on circularity and we can see that mainly through target-setting, both internal targets but also brand/industry alliances*". Accordingly, it is likely possible to position the current state of the fashion industry at 'Phase One' of the Pulse Curve, right beyond the initial application of uncoordinated actions with low improvements in environmental and social performances (Lehmann *et al.*, 2018). Consistently, according to Lenzing: "*We will see a lot of shift in business models, shift towards environmental-friendly and sustainable materials, while also*

durability will probably get much more important. So it might be that even though companies believe they sell less, the quality of clothing and fabrics will probably increase."

Indeed, as widely acknowledged, servitization features support profitability growth and expansion of customer base. "*A benefit that rental and sharing initiatives surely entail is the approach towards a different type of customer, which perhaps wouldn't even buy such products, because too expensive*", as unfolded by VF. In these regards, Chemical Recycler X also points out the critical role that chemical recyclers may play for the closed-loop exploitation of all those resources which cannot be avoided or reused anymore. However, in order to reach many circular objectives, the sharing of responsibilities, costs and benefits is fundamental. At Orange Fiber, they put collaboration among stakeholders among the prominent drivers for the effectiveness of the circular transition: "*The factors that might accelerate the evolution are on one side financial, on the other synergetic: alone it may be possible to move faster but the road travelled will be very short. Establishing virtuous cooperation partnerships, it is possible to truly achieve much more, integrating top competences for each phase of the process*".

In these regards, interview insights particularly outline the concrete barriers found in the development towards more closed-loop flows, which are the following:

- *Systemic*: Within the multifarious innovation of business models, there are companies that ride the wave of green washing or even stimulate an expansion in waste creation, which are difficult to identify given the lack of standards and reliable signalling forms. Particularly for chemical recyclers but not only, there is the complexity to push forth an innovative technology which doesn't perfectly match with the prevailing system's organisation and which doesn't have an already existing market. Furthermore, cooperation shall be demanded on all levels and especially at the design stage, in order to enable and influence changes both upstream and downstream

- *Financial*: Since many development steps require hard-tech innovations, as Chemical Recycler X states, "*the barrier which numerous players surely find is the difficulty for these technologies to scale up and become commercially viable, in the sense that there is the wide necessity for a great amount of capital and resources which shall derive from stakeholders with the same mission*". Higher costs relate also the inefficient scale at which these start-ups produce. All these expenses-raising factors sum up with the unpreparedness of the market, thus according to MUD Jeans "*the struggles are that you're doing something that 80% of the population doesn't understand and most people still buy clothing being price-driven.*"

- <u>Technical</u>: According to Lenzing, "*one of the most relevant barriers for closed loop fashion for recycling is the extreme amount of different materials used in the textile industry, the dispersion and diversity of fabric plants and the inaccuracy of labelling in garments (for example it does not show materials with a weight less than 2% and also all sewing threads or trims or other specific materials are not covered there). The second barrier also relates to the material itself because you don't really know what kind of chemicals has been used neither in the production process nor in the use process.*" Moreover, as Luxury Brand X further adds: "*Repairing in luxury is quite difficult, it could be viable for the most expensive garments but generally it is complex to create rental or reselling programs without hurting the idea of quality and strength of the brand.*"

In particular, the relevant role and current state issues of end-of-life management operators are strongly highlighted. According to Fibersort: "*The business case for collectors and sorters today bases itself in being able to sell as much as possible garments in the second hand markets, because their financial gains today come from the reuse industry either locally or exporting. One thing which is really unbalancing their business case and shrinking it is the fact that they seem to recover each time more volumes that they can't sell in second hand markets and this has to do on one hand with the increased disposal of garments (shorter cycles) and on the other with the lower quality in textiles themselves, but also because the second hand market is now starting to become saturated.*"

For what regards recyclers, according to Chemical Recycler X, "*Generally, the trends comprise a scarcity in virgin resources, which will likely spur prices up and cotton is already now a glaring example. Our objective is to offer a competitively positioned product, because we confidently know that brands won't be prone to spending much more, despite there are many reports asserting estimates of consumer willing to pay 10% more for sustainable products. In reality the logic joints between consumer demand and brands demand doesn't always function so well. However, the industry will form around the pricing of input and output materials as soon as it will be understood that our technology can generate new value streams across the two textile supply chains.*" Anyhow all these efforts will lose consistency and value if they won't find the support of a responsive regulative body and an acknowledged end consumer base. As VF specifies: "*The customer surely understands the concept of 'recycled' even though the expectation is that such an item shall cost less in respect to a completely virgin item, which is often unattainable because there are diverse costs which push the price towards the one of traditional products.*"

As widely acknowledged in the diverse supply chain perspectives investigated during interview, environmental certification, EPR systems and blockchain traceability will be fundamental to provide the right instruments for industry stakeholder. Specifically, Circle Economy unfolds: "*On EPR, we do advocate for it being implemented at national level, but we also do believe that this scheme will support the infrastructure for collectors and sorters, so you need it but only with extended producer responsibility you will not incentivise the whole value chain. Basically, you need to have a way of ensuring that the infrastructure is out there and is feasible economically to sustain, but then you need to balance it out with other incentives, such as reuse and recycling targets and incentives for green public procurement*". Accordingly, EVRNU states: "*If you can start putting responsibility on producer/designers, it will be then possible to widely increase the value of the discarder item*".

On the digital side of blockchain, according to Candiani it "*will be a great opportunity for fashion for sure because of the necessary advanced traceability*". Furthermore, Lenzing specifies: "*For us block chain technology is looking forwards to transparency, traceability and also enhancing a lot efficiency, which I think is the greatest driver*". Conversely, according to VF, "*it is very interesting, yet we collide against the complexity of the textile supply chain, where in some cases we reach tier 7 or 8, just for all the diverse steps and transfers present in this value chain. Many times specific raw material supplier may not even have access to the internet connection or to a computer. Thus the concept needs to be adapted to the manifold realities and at the moment it is still very tough to implement it along the whole supply chain*". However, there are interesting opportunities under development "*Genetic markets are extremely interesting because they would allow to have a clear view over the sources of the garments, especially in a full circularity perspective. This becomes critical in the moment the item is returned to get recycled: here hurdles may lie in counterfeit goods or in the presence of chemical products used during production. All these transparency instruments thus ease the complete tracing of a garment, explicating where it was manufactured, which were the transfers and how the recycling process may be safer*". Finally, Candiani further outlines: "*the importance of green certifications lately also pushed a boost in their number, leading to an obscure market of organisations falsely trying to make profit giving certifications without actually accurately controlling. Thus in this field, block chain may bring benefit to the truly sustainable and accurate certifications through the full traceability of flows and processes.*"

Generally, in respect to all these opportunities and hurdles, it is widely acknowledged that economic incentives and regulative support will play a fundamental role. Beyond this, blockchain technology, when applicable, is seen as the resolution factor against the loss of transparency and traceability typical of the large fashion supply chain networks.

A Blockchain-enhanced Product Stewardship Framework for the Fashion Value Chain

With reference to all insights gathered from state of art and practice as well as industrial interviews outlooks, the model shall be build up and tailored following the key logic of rendering sustainable and circular investments economically viable so to indirectly drive also industry-wide environmental sustainability enhancement.

Hence, the proposition aims at applying fees to textile and clothing producers for the sustaining of the infrastructure of collectors, sorters and recyclers; whilst also encouraging truly sustainable or circular individual firm initiatives. This blend shall empower sustainability champions and render less competitive unsustainable brands and producers along the whole value chain; in an attempt to dismantle traditional patterns of competition, production as well as consumption. The whole shift is then backed up by the digital layer embodied in the blockchain technology, which represents the facilitator of: required advanced traceability, control on the metrics for fees and discounts definition, fees payments fulfilment through smart contracts, visibility of useful reuse and recycling input data, brand transparency to be offered to more conscious customers. All aspects together sum up in the general goal of studying an innovative method for incentivising a widespread adoption of circular initiatives across the value chain, not only by sustainable leaders, but by any agent acting strategically for the persistence of his business.

Specifically, net fees need to be lower for companies deploying prevention principles, through improvement actions in the field of research & development, design and consumer education, in order to reduce the amount of resources produced and disposed every year. Each material shall thus be studied, developed and treated to satisfy more user needs for a longer period of time. In particular, the first and second aspect may work in a complementary and synergetic manner. Further on, as second priority, the framework shall incentivise reuse business models, through second-hand resale and re-commerce, leasing and loyalty programs, backed up by a system of reverse logistics. Thirdly, recycling is empowered by supporting the common infrastructure for end-of-life management. As a matter of fact, recycling is beneficial both for all the materials that are not possible to be prevented or reused, as also for the coverage of determined fibre performance requirements. Intelligent collection and sorting processes thus gains prominence in order to differentiate value and performance of each material, defining the relative circularity potential measures and consistently the best choice for the sake of both economic and environmental sustainability.

In these regards, blockchain architecture is ought to support both waste hierarchy application and operational framework hurdles overcoming, through the deployment of the following objectives:

- *Enhance potential for trust, SC collaboration and thus integration*
- *Connect usually separated players in secondary markets*
- *Minimise free riding issues*
- *Facilitate management of cross border flows*
- *Facilitate product deletion choice*
- *Enable direct rewarding*
- *Facilitate end-of-waste criteria evaluation*
- *Achieve higher social sustainability performances through SC integration and higher control both on companies and products*
- *Implement deep learning practices through the exploitation of RFID or genetic marker technologies*
- *Exploit decentralized control of BC to minimise surveillance requirements in the PS scheme*
- *Shrink the dark space of information unavailability during the use phase*

Furthermore, the base principle is the subdivision of responsibilities and flow typologies between single companies and centralised infrastructure initiatives. Each of the two parts will control the actions most fitting with its characteristic, financial and operational power. Single firms will thus be incentivised to act on the first two principles of the waste hierarchy mainly through soft tech innovations. On the other side, the centralised infrastructure will need to be subsidised to deal with hard-tech financially burdensome innovations in an aggregate way, expanding secondary markets and optimising the reverse supply chain structures.

The principles of economic convenience and polluter-pays shall be integrated with a much more accurate differentiation and individualisation for the allocation of subsidies, fees and discounts among cases of application. The fees are thus related to the single product, included in thoroughly differentiated categorization, and will also depend on the production levels and sustainability performances of each firm. Furthermore, as differentiation factor against the existing French EPR case, the level of coverage of fees is designed to vary according to supply chain position, given the diversity in bargaining power and ability in investing or also carrying out innovations. The stages paying higher percentages are the fibre production and more importantly the design & distribution stage, since brands are targeted as the key to propel revolutions

both upstream and downstream. In relation to the market failures encountered, the framework shall adjust them by incentivising the following factors: power disequilibria through more transparent, symmetric and trusty supply relationships; negative pollution externalities and overproduction through the allocation of fees, thus the increase of individual firm perspective costs aligning it with social costs to bear; asymmetric information through signalling options as green certifications and reputable alliances; transaction costs through blockchain efficiency and elimination of intermediaries.

Among the supply chain effects, the other features of the model are designed also to empower customers through information availability, attempt to drive their care habits and decisions for the end-of-life management of each garment. Given the structure of a hybrid blockchain, the scheme aims to act also in the formation of innovation hubs. Targeted consortiums would have indeed the power to accelerate progress by combining resources from multiple parties and aligning the key players needed for success in a focused effort. Supply chain effects shall thus be widespread from end to end, sizably changing production, consumption and competition patterns. As shown in figure ES.3, the deployment of waste hierarchy principles applied to the fashion environment with specific business models and operational settings, shall also drive an enhancement in profitability and value held in circulation, as well as supporting the trend in servitization. The more initiatives are drawn by companies towards waste prevention and reuse and thus towards the sale of performances, the lower will be the fees to pay. With this incentive scheme, value would be effectively circulated and redistributed across the whole industrial ecosystem.

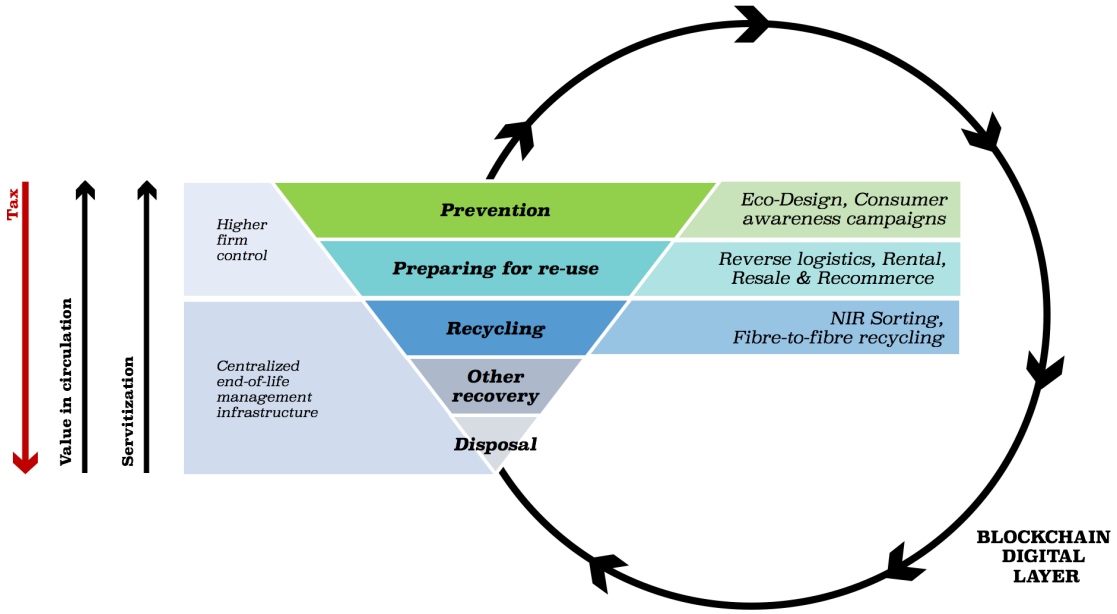


Figure ES. 3 - Incentives scheme structure developed

Validation

Given the complexity and heterogeneity of business models, products and systemic flows setting typologies encompassed in the framework, the implementation process is subdivided into 3 steps, adjusting to a gradual addition of modelling building blocks.

Hence, the scenarios analysed in the testing will be 4:

- **Business-as-usual**: Case in which the industry follows the current strategies.
- **Circular Stage 1**: Case of basic product stewardship scheme establishment, characterised by the sole collection of fees according to the polluter-pays-principles and directing them to collectors, sorters and recyclers, in order to scale up the reverse supply chain infrastructure and optimise it.
- **Circular Stage 2**: Circular Stage 1 conditions combined with the development of individual company initiatives, as reverse logistics, resale and rental business models.
- **Circular Stage 3**: Circular Stage 2 conditions combined with the application of eco-design principles and consumer awareness raising initiatives, thus fulfilling the first principle of the waste hierarchy through waste prevention.

These are applied to a case at applied to a case study, which is validated both from an economic as also from a life cycle assessment perspective, basing on the impactful product category of jeans, specifically made from the pioneering circular brand MUD Jeans. Accordingly, a first thorough analysis was carried out for the estimation of differentiated flows percentages for each scenario, which would be then applied in both sub-tests.

Upon this, the 'Financial Viability Test' is constructed building approximate profit & loss statements till the computation of EBITDA values, for supply chain each actor in each scenarios, as well as allocating subsidies, fees and discounts. The diverse strategic alternatives are then compared according to EBITDA trends and approximate NPV values. The general outlook of value chain actors' conditions enlightens a preferability for the full application of the model, through the integration of all building blocks, as shown in table ES.1. The problem relates to the main rebound effect of circular economy systems of disadvantaging of raw materials suppliers in relation to the higher circulation of existing resources. Beyond this, the validation process definitely demonstrates the value of differentiated incentive approach, in which to facilitate both end-of-life managements infrastructures and single firms in the direct supply chain. Accordingly, the test provides proof for the robustness and significance of the full application of the novel framework proposed.

NPV	***BAS***	***CS1***	***CS2***	***CS3***
Fibre Producer	41.536 €	45.794 €	30.143 €	35.039 €
Fabric Producer	536.447 €	552.910 €	669.442 €	683.510 €
Retail Brand	2.976.156 €	2.816.091 €	9.244.057 €	10.813.915 €
Collector & Sorter	-51.624 €	-	-	-

Table ES. 1 - Approximation of NPV values for each supply chain actor in each scenario of the 'Financial Sustainability Assessment'

On the other hand, the 'Environmental Sustainability Test' is built on a Life Cycle Assessment analysis deployed through the software Simapro. Here, the entire supply chain outlook is tested diversifying among the applications of the 4 scenarios analysed. The inherent mechanism to test is thus the effectiveness and the width of impact of a modification in the diverse possible product and waste flows percentages on the increase in environmental performances, once a certain value redistribution scheme is put in place.

Also in this case, results generally favour the full implementation of the model, thus the reaching of Circular Stage 3. Looking in particular at figure ES.4, which displays the results for the macro- impact categories of '***Human Health***', '***Ecosystems***' and '***Resources***', it appears how, even just qualitatively, the improvement carried by the framework is significant (delta between the red column and light blue one). Specifically, the positive differential gains massive magnitude within the transition from Circular Stage 1 to Circular Stage 2, thus concretely demonstrating the potential of a more widespread application of the waste hierarchy principle of 'Reuse' throughout the fashion supply chain.

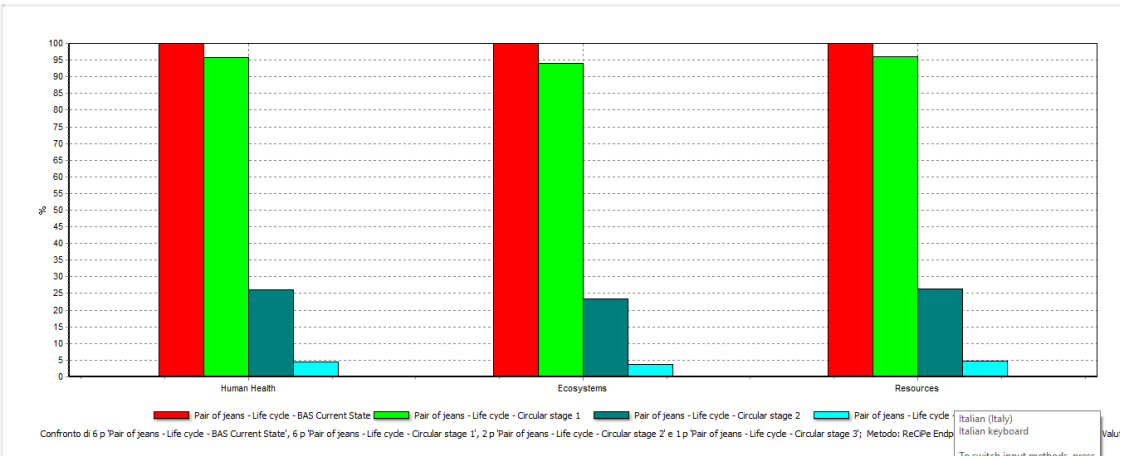


Figure ES. 4 - Macro-impact categories results of the Life Cycle Analysis for the 'Environmental Sustainability Assessment'

Conclusions & Limitations

In conclusion, the comprehensive research evolution leads to the resolution of the stated research questions, as follows:

- ***RQ1. What are the causes for a fashion industry state in which it is now plenty of circular business model tools but there is still no wide diffusion of strategic circular approaches?*** --- This first inquiry was answered through the critical analysis of the state of art and practice. Specifically, the limitation in widespread adoption of closed-loop business models and the presence of rare cases of sustainability champions, related to technical, economic, systemic and regulative stumbling blocks. The competition patterns of the fashion industry and the complexity present in the related supply network cause the loss of transparency and the diffusion of unsustainable business practices, rendering it difficult to understand where to act in order to improve systems circularity (See **Sections 1.1.2. – 1.2.4.**). The fast-fashion demand requirements as well as care and disposal habits of consumers lead to unmanageable volumes of waste, where the decline in quality translates in insufficient reusable fraction for collectors (See **Sections 1.1.1. – 1.1.4 – 1.2.4. – 2.7.**). The nature of textile fibres and the tendency to design clothing with fibre blends and aggressive finishing treatments makes recycling a complex process that needs time to be developed and optimised (See **Section 1.2.4. – 1.2.8**). Furthermore, the switch towards circular business models comprises large change management efforts and burdensome financial requirements, especially in regards to the commercialisation gap, where informational asymmetries particularly hamper the relationship with lenders (See **Section 1.2.4**.). In respect to reverse logistics and enabling digital technologies there is also an obstacle linked to missing technical skills and competences (See **Sections 1.2.7. – 1.3.3**.). Generally, a great gap leading to uncertainty for the circular development is the lack of standardisation in terms and policies as well as the current inexistence of reverse supply chain related markets (See **Section 2.6**.). Finally, the maybe most relevant prerequisite is a top-down support scheme for the overcoming of operational hurdles (See **Sections 1.3.3. – 2.11**.).

- ***RQ2. What possible scenarios of consumption and production patterns will be enabled in the near future by the upcoming technologies?*** --- This second inquiry is answered through diverse insights gathered in the 16 interviews deployed. Also in the concrete field of operating fashion supply chain companies it is rather straightforward that current production, consumptions and disposal patterns do not provide long-term persistence. The progressive shortage and price increase for virgin raw materials is widely acknowledged. Hence, it goes

without saying that a strategic turnaround will be necessary. Ecosystems boundaries will demand an improvement in research efficiency which will translate for companies in sustainable sourcing, reuse business models and the transition from an economy based on the sale of goods to one based on the sale of performances. Upcoming technologies in NIR sorting, chemical fibre-to-fibre recycling and digitalisation accordingly enable a scenario where supply chain players drive the circulation of materials and provide enhanced services to more conscious consumers.

- ***RQ3. How would it be possible to effectively incentivize companies towards closed-loop developments?*** --- The final inquiry is answered through the development of the model. As anticipated above, the instrument required to provide effective incentives and drive the transition of companies is a product stewardship scheme, in which subsidies, fees and discounts shall be much more extensively individualised on the specific business case. The categorisation of products and performance indicators shall thus be exhaustive and any player shall see clearly the benefits related to determined strategic actions to be implemented.

The limitations mainly refer to the unavailable or limited information for various categories of data, as well as for rebound effects quantification. The novelty of topics links indeed to the inability of companies to share information, either because sensible data are tapped or because they are not even informed or conscious in regards to certain topics. On the other side, rebound effects regard possible outcomes of enhanced consumption, fibre degradation, altered competition patterns and higher transportation levels.

Essentially, this dissertation and test aims at representing a basis of discussion for policymakers. Comprising all limitations, it shall be used as introductory reference on which to build up more concretely applicable and testable solutions, upon further research as also availability of greater and more reliable databases. In particular, in respect to fibre degradation a parameter analysis shall be carried out within the boundaries of the life cycle assessment, in order to evaluate the potential outcomes along a defined timeline. Moreover, extensive studies shall be deployed for estimating the effects on price and demand patterns of the development of markets for collectors, sorters and recyclers. More in general, the objective shall be to unfold the relations among price convenience and demanded volumes variation, also in connection to the allocation of fees and incentives, implemented in the framework. In conclusion, it shall be assessed if and how the model may be possibly applied to other sectors with similar fragmentation and complexity of the supply chain network.

Introduction

In such an ever-evolving environment, continuously filled up with novel inventions and fruitful innovations and strained towards ceaseless economic growth, one should be aware of being tempted to sight panaceas in place of amorphous business models as also empty glasses in place of noteworthy pots of gold. The global ecosystem maturation intrinsically entails severe trade-offs in favour of the improvement of a specific subset of performances, at the cost of aggravating impacts in other areas, inaccurately assumed less strategically relevant for the business. Revolutionising technologies thus come and go at a progressively dynamic rate, solving peculiar aforethought as also unpremeditated issues, while simultaneously raising the need for additional diverse solutions, as in an interminable Babushka doll. In this context it becomes paramount to find accurate qualitative and quantitative instruments in order to critically estimate economic, environmental and social value of each innovative conception.

The fashion industry offers an emblematic example since the advent of the sewing machine and automated manufacturing systems pushed the shift from the provision of high-end goods for elites to the mass production of commodities for consumerist masses, which implied a great variety of consequences. The apparel market in particular expanded tremendously, offering functional protection and psychological individuality expression to all social classes worldwide, boosting financial flows among developed and developing countries and tickling many related economic sectors. On the downside, this quick and negligent expansion caused also detrimental effects on the natural environment, unmanageable demand of non-renewable raw materials, unhuman conditions of labour and one of the most complex and nebulous supply networks. The overall result is the attainment of second place among the most polluting industries, with clothing and footwear producing 8,1% of global CO_2 equivalent emissions in 2018 (Quantis, 2018). The lack of transparency and trust further complicates the design and implementation effectiveness of redeeming actions. In the last years there have indeed been manifold ground-breaking cases of enterprises advancing the sustainability level of either production processes, products or corporate governance policies. Still, single-issue or single-company ameliorations failed to drive a widespread effect and influence on the overall industrial horizon, leaving a large

improvement gap to be filled through more complete and sustainability- as well as technology-oriented regulative interventions.

Given the considerable economic, environmental and social impacts over the whole global society organisation, the fashion system appears to be of serious relevance to be studied through a multifunctional and multilevel approach given the heterogeneity of complications involved. In fact, although there are studies dealing with sustainable business model innovation (BMI) in the fashion industry (e.g., Beh, Ghobadian, He, Gallear, & O'Regan, 2016; Kozlowski, Searcy, & Bardecki, 2015; Lueg, Pedersen, & Clemmensen, 2015), they usually lack an integrative, holistic perspective (Todeschini *et al.*, 2017). It will be consistently necessary to amplify the research field boundaries in order to encompass theories related to firm organisational structures, product flows design, financial control, logistics optimisation, supply chain management, technological disruptions, legislative frameworks, market regulations and sustainability assessments. All these topics shall be examined at the micro-level of individuals and firms, at meso-level of supply chains and especially at macro-level of industries and economic systems, with the aim of providing the correct incentive measures for each pertinent stakeholder.

This dissertation will in particular build upon the application of the 'polluter-pays-principle' for the sake of discouraging harmful behaviours and enforcing ecological influences, defining it as the allocation "*of costs of pollution prevention and control measures to encourage rational use of scarce environmental resources and to avoid distortions in international trade and investment*" (European Commission, 2012). In addition, 'Sustainability' is assumed, among the numerous definitions, as "*the persistence over an apparently indefinite future of certain necessary and desired characteristics of both the ecosystem and the human subsystem within*" (Hodge, 1997). Specifically, the persistence will be assured when all systems and resources are able to function properly, adapt to each other conditions and be transformed into increased overall value without harming the possibility for future enhancement of circumstances. Among "*certain necessary and desired characteristics*" it is possible to characterize the three economic, environmental and social sustainability pillars, which if accomplished together embody the triple bottom line model (Elkington, 1994). The analysis will partly tackle the issues of social unsustainability but then predominantly dig into the first two pillars, in order to develop a framework based on the useful synergies between the two. In respect to this, the most promising action areas defined in the Pulse of the fashion industry report are: Sustainable Materials Mix, Closing the Loop, and Industry 4.0 (Lehmann *et al.*, 2018).

The research will thus investigate the appealing concept of circular economy (CE) as driver of sustainability, defining it as: "*an economy that is restorative and regenerative by design and provides benefits for business, society, and the environment. It entails gradually decoupling economic activity from the*

consumption of finite resources, and designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital." (Ellen MacArthur Foundation, 2020). This will be further linked to the concept of waste hierarchy, thus a priority order to be applied to all policies and Member States economic activities, favouring '*prevention*', '*preparing for reuse*', '*recycling*', '*other recovery*' and only finally '*disposal*' (EC, 2019). The merging of these paradigms shall indeed facilitate the achievement of complete sustainability performances improvement potential of CE models.

As a matter of fact, CE may play a revolutionising role it in the fashion environment, where every year $500 billions of worth that may be recovered are irreversibly lost, due to clothing underutilization and lack of textile recycling (VF, 2018). When closed-loop supply chain management combines with waste hierarchy inspired business models, it seems reasonable to foresee success for the resolution of incumbents' current state issues. Principles as waste prevention, preparation for re-use and recycling evolve indeed into models of eco-design, resale, rental and fibre-to-fibre recycling which usually embody new alternative revenue streams, driving a higher profitability than traditional business-as-usual tactics. Remarkably, the transition will be effective when circular initiatives will be embraced both in upstream and downstream processes of the majority of firms, thus both within sustainable supplier relationships as well as within marketing strategies (Urbinati, Chiaroni and Chiesa, 2017a). In order to reach that level of widespread adoption it will be necessary to bear significant investments, temporary high operational costs and various change management difficulties. Since Circular Economy is considered a strategic prerogative for the competitive future persistence of fashion industry players (Foundation, 2017; Reverse Resources, 2017; VF, 2018), it will be desirable to accompany the transition through top-down initiatives, solving systemic barriers and incentivising an accurate prioritization of sustainability-oriented projects.

The synergetic relation of economics and environmental performances is concretized through the deepening of product stewardship schemes, where a determined combination of taxes and subsidies facilitates the reduction in pollution levels and the escalation of an adequate infrastructure, which then also favours economic returns, in the form of either competitive advantage wins or efficiency savings.

Still, these regulative solutions usually feature wide implementation stumbling blocks, failing to reach the designed market and industry effects. Hence it becomes crucial to merge this macro-level top-down legislative perspective with a technological point of view, currently proposing a great variety of digital disruptions. Manifold technologies are now on the edge of further expansion, remaining blocked in the piloting phase, but which may actually disrupt entire market settings and relations if accurately supported by the right incentives.

In these concerns, it is fundamental to understand whether there are market failures, such as market power, externalities, asymmetric information or transaction costs; which may hamper the correct and efficient functioning of the market structures (Medema, 2004). Under these assumptions, digitalisation effectively entails the potential to render transactions more fluid, align knowledge and facilitate pollution-reducing activities.

Relating to the application of extended producer responsibility schemes in the fashion environment, the main barriers relate to the width of supply networks and goods' transfers, to the complexity of traceability from fibre to garment till end of life and to the unbalanced relations among supply chain players. In respect to these hurdles, block chain architecture may provide a higher control on flows of goods and sustainability performances, enabling better centred actions. Indeed, according to a recent McKinsey article, especially for supply chains where participants are not known or trusted, the distributed ledger technology can add trust, transparency, and traceability. Almost by definition, these supply chains are complex, multi-tiered, involve many parties, and they operate in a regulated environment that demands a higher level of traceability. Whilst, on the other side, for supply chains with known and trusted players, a centralized database approach is generally more than adequate. This does not mean that all these supply chains currently follow a true end-to-end approach, and in fact, many of them use siloed databases that contain data with only limited traceability (McKinsey, 2020). Thus, it is rather the industry structure and propensity to market failures, which drives the need for advanced traceability and in this case block chain effectiveness. The design of related projects will therefore need to be calibrated according to the specific needs of each supply chain and customer base. The democratization of access and of trust (Pawczuk, Massey and Holdowsky, 2019) may empower conscious consumers and innovative sustainable fibres' producers to drive a behavioural change in the retail stage, thus consistently urging both upstream and downstream disruptive effects. In detail, such a system transition shall be facilitated by a hybrid type of blockchain, allowing full access to the key supply chain actors which will be provided with both a private and a public key, whereas granting limited access to a wider base of permissionless stakeholders. According to Pawczuk *et al.* (2019), such hybrid coopetition consortia require a shift in mind-set: "You must ally within your ecosystem—whether direct competitors or not—and work toward some greater good" (Pawczuk, Massey and Holdowsky, 2019). Thus a great change management effort will be required in all the participating companies, both in regards to block chain and circular economy, and will need to be qualitatively evaluated to concretely reach the objectives set.

Finally, it goes without saying that what some see as a panacea reaches the desired outcomes only if designed in order to fully solve the manifold improvement gaps. With the aim of assessing the features for an effective framework conception, on-field business interviews have been carried out

along the whole process of work development for investigating and then testing the economic and technical viability of various promising technologies and business models. Positively, in general, the trends and themes considered for the dissertation appear to represent a critical priority in all interviewees' strategic agenda for the forthcoming years, demonstrating the current lack of solutions and the congenital need for an ecosystem that supports transformational innovation and disruptive business models.

Hence, the structure of the paper will follow a fil-rouge spun by blending scientific literary footing with concrete business world perspectives along its whole length. In connection to this, the objectives and research methodology will be displayed at first. The intention to support the sustainable fashion revolution through factual technological and managerial rationales, responding to the needs of tomorrow with a brainstorm of today's edgy innovations, pushed the choice of the topic. This evolved into structured research questions and then was concretised through the deployment of specific research criteria and analysis methods.

Secondarily, the state of art and practice will be exposed in ***Section I***, mixing scientific literature with grey literature, in order to gain all necessary futuristic insights for the sake of the evolution of truly implementable propositions. Each of the arguments investigated will be then supplemented with on field industrial outlooks, unwound through 16 qualitative interviews, within ***Section II***. Both Sections 1 and 2 will comprise parts necessary for the description of study boundaries and for the definition of literature gaps as also parts functional to the establishment of frameworks building blocks. Moving on, ***Section 3*** will disclose the result of the whole work of research and development of a framework aiming to improve fashion system sustainability performances through circularity principles, driving the widespread transition of supply chain actors through the use of product stewardship schemes and enabling the whole technical functioning and desirable effectiveness achievement through the exploitation of advanced digitalisation technologies. Consistently, the implementation potential will be tested in ***Section 4*** with the support of a paramount case study and two types of assessment methods, in order to deeply dig into the concrete fashion businesses' fabric.

Objectives, research questions and methodology

According to the author's knowledge, current literature provides extensive analysis of single models and single topics but lacks of a more comprehensive integrative perspective. Particularly, the state of the art and practice conclusions point out the urgency to act on fashion supply chains' leanness, flexibility, social and environmental sustainability, as well as lack of traceability. In these regards, circular economy business models do provide a competitive and promising supporting tool. A specific regulative evolution of such end of life extension proposals lies in product stewardship schemes, which are required in order to precisely set responsibilities, incentives and charges; implicitly inducing widespread improved behaviours from all types of stakeholders. On the other side, closed loops flows management may be enabled by greater access and control over data and amelioration options. One way to achieve this type of transparency is through the exploitation of blockchain technology, which is diffusely upheld especially in the fashion ecosystem, since supply network relations are particularly complex, asymmetrical, blurred and missing trust. From a general perspective, the conceptions enounced are clearly characterised by both pros and cons. Single solutions might effectively support single issues, but the true potential may be empowered through the integration of disparate strengths and opportunities. Only the right fit of paradigms, technologies and policies will thus permit the creation of true synergetic effects, enhancing overall value creation, extraction, capture and recovery.

Aiming at these goals, there is still extensive research to be carried out in order to clear up the application and interoperability of diverse theoretical as also practical models into diverse business scenarios. In respect to this, the literature review work reveals either complete absence or limitation in addressing the following matters:

1. *Consolidation of diverse solutions for the application of waste hierarchy principles into a multi-scenario model*
2. *In-depth analysis of the impact of economic incentives on building up infrastructures' scale, facilitating specific markets growth and eventually improving environmental performances*

3. *Exploitation of blockchain technology for regulation and governmental control purposes*
4. *Role of servitisation in EPR applied to the fashion ecosystem*
5. *Impact of business relationships quality on innovation propensity and worth, especially in fashion*
6. *Impact of value redistribution effects along the supply chain, in relation to the sharing costs, benefits and responsibilities in a supply network or EPR scheme in a calibrated manner*
7. *Detailed studies of economic issues and technicalities for end of life managers, in particular collectors*
8. *Impact of new sorting technologies on market potential of reuse and recycling markets. Likewise, eminent role of chemical recycling technologies*
9. *Variety in quantitative LCAs studies*
10. *Impacts of rebound effects related to the single conceptions and integrated effects of diverse rebound effects merged*
11. *Imperfect effectiveness of other current textile EPR schemes, especially in respect to the factors enabling an exhaustive classification of cases (discounts and general item categories)*
12. *Consideration of more concrete business feasibility factors through on-field information*

Generally, there are various theories displaying apparel industry issues either in connection to digital technologies or in connection to circular initiatives and extended producer responsibility principles, but these aspects never fully merge. The largest and most relevant gap found in present literature is thus the missing combination of solutions originating from diverse fields, in particular due to the rawness of enabling technologies. The precocity of the topic appears evident against current achievements, whereas it rather seems an urgent exigency in terms of global targets for the near future. Hence, the objective of the dissertation research is to:

•

Establish a link between regulative policies and technologies exploitation, in order to develop a framework characterised by well-aimed adaptation to the business context, concrete implementation potential, incentives effectiveness and ability to drive widespread balanced consequences throughout the whole fashion value chain.

•

The aim will be to respond to literature gaps 1, 2, 3 (partly), 4, 5 (partly), 6, 7, 8 (partly), 9 (partly), 11 (partly), 12. The framework shall thereby be designed for the minimization of fashion waste, especially at post consumer level, through the following of the waste hierarchy in connection to the polluter-pays-principle. Consistently, the model developed shall provide an ecosystem which supports transformational innovation and disruptive business models. The key will be rendering sustainable and circular investments economically viable so to indirectly drive also industry-wide environmental sustainability enhancement. Basically, the proposition aims at applying fees to textile and clothing producers for the sustaining of the infrastructure of collectors, sorters and recyclers; whilst also encouraging truly sustainable or circular individual firm initiatives, such as eco-design, rental and resale business models, reverse logistics, supply chain innovation and consumer awareness campaigns. This blend shall empower sustainability champions and render less competitive unsustainable brands and producers along the whole value chain; in an attempt to dismantle traditional patterns of competition, production as well as consumption. The whole shift will be backed up by the digital layer embodied in the blockchain technology, which represents the facilitator of: required advanced traceability, control on the metrics for fees and discounts definition, fees payments fulfilment through smart contracts, visibility of useful reuse and recycling input data, brand transparency to be offered to more conscious customers. All aspects thus together sum up in the general goal of studying an innovative method for incentivising a widespread adoption of circular initiatives across the value chain, not only by sustainable leaders, but by any agent acting strategically for the persistence of his business.

In these regards, aiming at the elaboration of most current literature gaps found, the delineated research questions (RQ) will be the following:

- ***RQ1. What are the causes for a fashion industry state in which it is now plenty of circular business model tools but there is still no wide diffusion of strategic circular approaches?***

  This question perfectly aligns with the main research objective set out. It shall address the factors hampering the transition from Phase One to Three in relation to the steps displayed in the Pulse Curve (Lehmann *et al.*, 2018). Hence, the focus will be on the stumbling blocks between a state of separate companies empowering dedicated resources, setting targets, directing efforts toward creating visibility into the supply chain; and on the other side a state characterised by the scaling up of collaborative advanced solutions and improvement measures to increase profitability as well as environmental and social performances (Lehmann *et al.*, 2018).

- ***RQ2. What possible scenarios of consumption and production patterns will be enabled in the near future by the upcoming technologies?***

  This question mirrors the missing settlement of required digital and physical recycling technologies and thus the lack in literature of studies regarding the possible consequences and impact radius of such innovations. All of these entail indeed the potential to disrupt fields also externally to the desired implementations, to let unexplored markets swell and to modify deeply rooted consumer behaviours and mental conceptions.

- ***RQ3. How would it be possible to effectively incentivize companies towards closed-loop developments?***

  This final question highlights the complexity in defining regulative policies, aiming to reach the desired objectives in reality. Accordingly, it will be necessary to carefully evaluate the needs of each actor, i.e. the specific business model, technological disposition, supply chain partners and employees' organisational structure. Each case will plausibly require different measures to be incentivised towards certain targets and activities, leading to the necessity for a meticulously differentiated framework.

Methodology

The resolution of the above-stated research questions demands the following of an adequate research methodology applied to a precise research scope. Specifically, ***RQ1*** will be answered through the process of heterogeneous insights gathering from the analysis of both the state of art and practice, where diverse factors have relevance in inhibiting the full adoption of circularity principles. Secondarily, ***RQ2*** will be answered through the investigation process carried out within the on-field interviews, given the fact that the novelty of topics is high and it is necessary to acquire knowledge regarding visions and strategical perspectives of operating firms. Finally, ***RQ3*** will be answered through the creation of the model, where the assessment of different supply chain actors' organisation, tactical objectives and requirements enables the understanding of the key areas on which to act in order to provide effective incentives.

For what regards the research scope, the boundaries of the analysis entail the whole fashion apparel supply chain, focusing on textile fibre inputs for garments' manufacturing, within a European geographical horizon. This choice was driven by the forecasted potential effectiveness of textile-to-textile recycling for fashion when put in connection with the upcoming innovative chemical reprocessing technologies. The spatial boundaries, on the other side, reflect a particular regulative framework as the one of the European Union, which is very different from other worldwide economies. Its keen orientation towards continuous improvement in sustainability performances both for process and industrial structures, drives the fixation of challenging targets for the enhancement of circular flows in all economic sectors and the on-going definition of an accurate strategy for the evolution of the fashion ecosystem. In particular, the workwear market will be excluded from the investigation field because it is characterized by own specific stumbling blocks for the efficacy of circular alternatives. According to Europe's leading manufacturer of polyester-cotton fabrics for workwear with requirements of fireproof, high visibility, chemical protection: "The major general hurdles found in the recovery of textile fibres currently are: chemical contaminations present during reuse, permanent colouring obliging to carry out expensive sorting activities, residual resistances of recycled materials not always compatible with workwear destinations. Then also materials made of chemically recycled polyester have

limitations that need to be deepened. Given the lower dynamometric resistance and abrasion resistance of fibres, recycled products will have a much lower life expectancy than what regards virgin materials and on the other side the release of micro-plastics during use is enhanced." (Alfonso Verdoliva, Klopman). Thus all these and other acute technical stumbling blocks will need to be addressed through a more tailored approach, given also the diverse structure of competition among the predominant firms within this market. As a result, the field of apparel to analyse will focus on the production of clothing for normal lifestyle, functional and also fashionable use purposes.

Furthermore, the research then grasped a manifold variety of outlooks from different study fields outside the fashion environment in order to obtain and integrate truly innovative propositions. This becomes particularly evident within the literature review section.

State-of-the-art framing and analysis procedure

Aiming at the thorough evaluation of all the possible beneficial modelling features applicable to the fashion supply chain structures, the review of the state of art combines scientific literature and grey literature in an integral way, in Section I. During the process, journal articles, books, company reports and websites were inspected. Insights were then merged in a separate document in order to assess the validity of each theory or instrument, consolidate findings and gather more general conclusions. A first part of the documents and the relative review was necessary to outline the background and future panorama of visions, more concretely defining the problems and laying the foundation for solid research questions and model propositions. Whereupon, a second part was useful for investing how to effectively incentivise companies towards proposed objectives and thus how to more accurately structure the model.

The comprised topics refer to different branches of fashion environmental issues, challenges, business models; circular economy models, drivers and barriers; excess management paradigms, current limitations and future potential solutions. In particular, the main specific keywords used in the research phase were: 'Environmental impacts of fashion industry'; 'Sustainable fashion'; 'Business model innovation'; 'Textile and clothing industry'; 'Apparel'; 'Sustainability'; 'Fast fashion industry'; 'Waste management'; 'Resource efficiency'; 'Material efficiency'; 'Circular economy'; 'Recycling'; 'Closing the loop'; 'Circular economy business models'; 'Upcycling'; 'Collaborative consumption'; 'Eco-design'; 'Ecolabels'; 'Life cycle assessment'; 'Second hand clothing'; 'Reuse'; 'Rental'; 'Resale'; 'Product service systems'; 'Product deletion';

‘Sustainable supply chain management’; ‘Operations excellence’; ‘Sustainable reverse supply chain’; ‘Reverse logistics’; ‘Closed-loop supply chains’; ‘Drivers’; ‘Barriers’; ‘Supply chain collaboration’; ‘Sustainable production’; ‘Industrial symbiosis’; ‘Index methods’; ‘Blockchain’; ‘Digitalisation’; ‘Industry 4.0’; ‘Internet of Things’; ‘Extended producer responsibility’; ‘Product Stewardship’; ‘EU Waste Framework Directive’; ‘Life Cycle Management’; ‘Systemic change’.

The selection of documents followed principles of validity and significance (assessed through the use of Scimago website, favouring papers graded within first quartile Q1), temporal proximity and accuracy of content in relation to dissertation objectives. The documents were then organised in three macro categories, in order to more consistently address each theoretic principle, technology or business model carried out and combined with other contributions according to determinate objectives.

In particular, the first chapter investigates fashion industry current state and future prospects (**See Section 1.1**.), progressing through: its historical developments and driving trends, the supply network structure and pressures, hidden costs and sustainability issues, waste creation statistics, upcoming declines in EBIT for business-as-usual scenarios and the growth of green consumerism, which is the primer for the whole potential solutions’ effectiveness in limiting pollution and enhancing resource efficiency. Hence, the objective of this chapter is to explore the factors of such a detrimental current state and sunder opportunities that are reflections of inconsequential green-washing from the ones that may solidly push the widespread tangible transition of apparel industry stakeholders towards greater long term sustainability.

Secondarily, the potential of circular economy (**See Section 1.2.**) applied to fashion has been inspected through the study of: circular economy definitions, circularity gap, resource efficiency, waste hierarchy, closed loop solutions for fashion products value extension, drivers and barriers; circular business models such as sale of performance, ReSOLVE, eco-design, leasing, sharing; circular supply chain management through sustainable SCM, SC integration, multi-stakeholder collaboration, operational excellence, service orientation; digitalization & industry 4.0 within waste management innovations, the fundamental role of Block-chain, transparency and traceability as well as eco-labels; and finally the technologies for textile reuse and recycling providing futuristic innovations, economic viability, quality management. In this case the objective was to define which circular models best fit with fashion supply chain requirements and thus which priority system shall be incentivised.

Further on, chapter three depicts waste management theories (**See Section 1.3**.) born aside from circular economy and then amalgamated with it. In respect to this, the analysis provided an overview of European directives and strategies, then flowing through reverse logistics’ definitions, drivers and barriers, change management, impacts for the fashion industry; industrial

symbiosis architectural innovation, variables for efficiency and effectiveness, win-win conditions; Extended Producer Responsibility definitions, role in counter-balancing market failures, different characteristics and typologies, limits and failures, solutions and effectiveness for circular economy implementation and sustainable development. Hence, the objective was to assess the effectiveness of various excess management systems and to unfold the most promising methods to structure the incentives for the priority system determined above.

Finally, figure 1 depicts the progress of considerations gathered starting from the thorough analysis of the state of the art and practice.

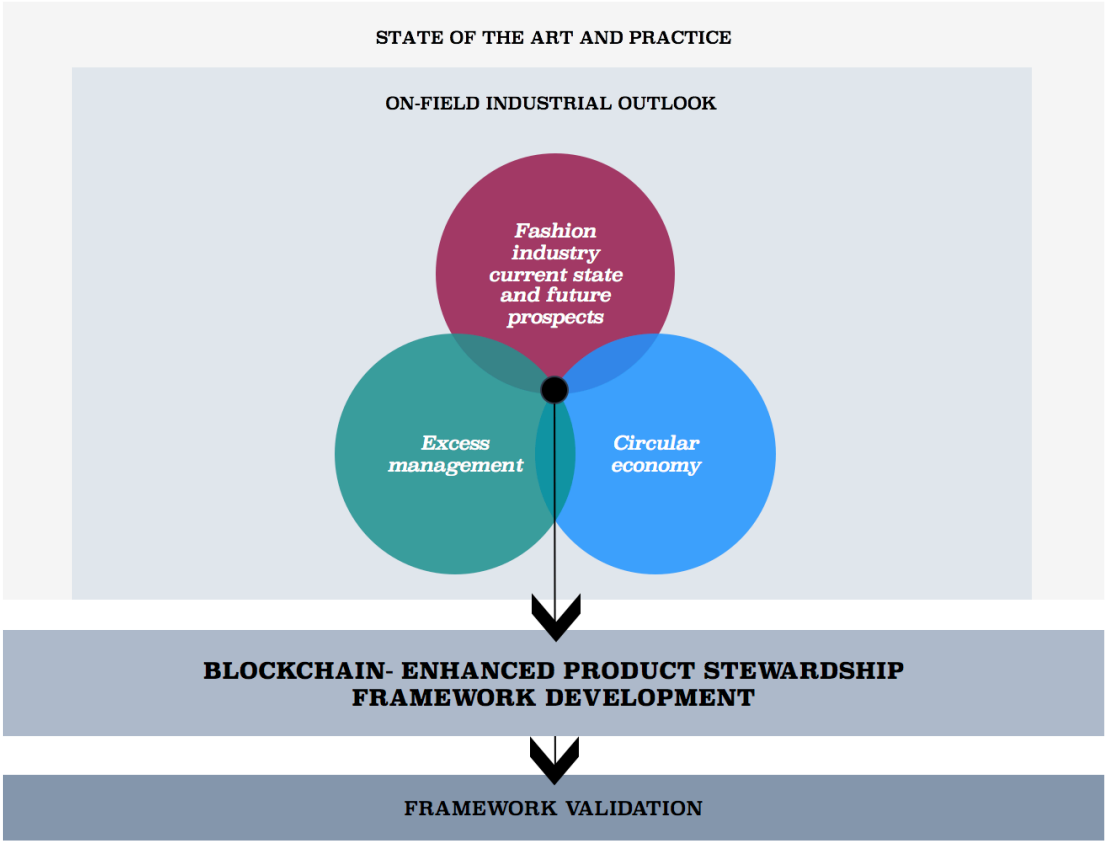


Figure. 1 - Framework development diagram

Basically, the triple investigation basis of 'Fashion industry current state and future prospects', 'Circular economy' and 'Excess management' models is first assessed through the review of scientific papers and company reports, but is then complemented by on-field interviews, in order to comprehensively provide the key for the development of the model and thus the design of the validation processes. Only at the intersection of all those paradigms, technologies and regulative approaches it is indeed possible to sight the complete gaps of improvement and to find possible concretely constructive solutions.

Hence, aiming at the provision of constructive primary information, 16 interviews have been carried out, either with physical presence or through video conference. The intended objectives were:

- *Resolve last identified gap in the literature review, referring to the lack of consideration of more concrete business feasibility factors*
- *Analyse diverse positions, drivers, barriers and strategic standpoints of different players for each value chain stage*
- *Confirm or disprove theoretical assumptions found in present literature*
- *Investigate current state of the fashion industry sustainable development*
- *Investigate presence of fruitful collaboration and prominence of co-innovation projects*
- *Investigate the feasibility of digital and recycling technologies in the textile and clothing environment*
- *Investigate the viability of extended producer responsibility schemes and fiscal incentives for investments*
- *Extract strategic, environmental and economic data for the formulation of the two-fold analysis approach for the validation of the proposed framework*
- *Qualitatively evaluate the proposed framework*

This section will thus be constituted by the integration of state of the art confirmations, deviations as well as innovative proposals, still not studied scientifically, but promising wide issues solving potentials.

The choice of participants comprised a non-probability convenience sampling process, basing on author's contacts and web researches among which mostly European sustainability-oriented companies replied. The sample will thus be less representative of the entire population under examination, referring to the entire fashion industry. However, given the specificity of cases interviewed it will be more likely to access insights of future trends and innovative business models. In addition, when possible, the interviews addressed more than one informant per firm, in order to avoid convergence and biases in the answers.

The next table will display a description and characterization of interviewed firms.

Firm	*Number of interviews per firm*	*Supply chain position*	*Description*	*Specific goal*	*Country*	*Foundation year*
Lenzing AG ***(1)***	2	Fibre producer, Recycler	International group producing wood-based fibres and filament yarns: viscose, modal, lyocell. Often taken as reference for textile market insights and sustainable initiatives. Patented REFIBRA recycling process produces new TENCEL fibres from high-cellulosic scraps.	Assess textile supply chain current state and key sustainable growth directions. Analyse REFIBRA recycling process economic and environmental performances, as well as scaling up potential	Austria	1938
Orange Fiber ***(2)***	1	Fibre producer	Innovative start-up producing a silk-like fibre and blended textile, from an open-loop recycling process of citrus fruits juice production leftovers. Supported by Global Change Award, launching collaboration with Salvatore Ferragamo, gain of €650.000 through equity crowdfunding campaign.	Assess potential of open-loop circular options for what regards the supply of inputs	Italy	2014
Brugnoli Spa ***(3)***	1	Fibre producer	Italian quality fibres and fabrics producer, building up on traditions and continuously innovating processes and raw materials. Wide range of sustainable alternatives, from recycled to bio-based materials.	Integrate diverse sustainable strategic perspectives, focusing on the key role of biodegradability	Italy	1952
Klopman International ***(4)***	1	Fabric producer	Developer of workwear poly/cotton fabrics selling to protective-wear, corporate-wear and workwear markets.	Investigate the applicability of closed-loop alternatives for the workwear sector	Italy	1967
Candiani Spa ***(5)***	2	Fabric producer	World's finest and most sustainable denim mill creating the fabrics that gave birth to the Premium Denim Industry. Embodying all tradition and innovation values of Made in Italy, it sells to the most prestigious brands on the market	Assess middle supply chain position actors' innovation power and dependence on other stakeholders. Validate the framework proposed	Italy	1938

VF Corporation ***(6)***	1	Apparel & Footwear Holding	Purpose-driven giant corporate group with more than 30 brands subdivided into Outdoor, Active and Work. Exemplar reference for change management, sustainability and responsibility strategies and continuous research & development.	Assess fashion supply chain current state and key sustainable growth directions. Explore potential of reuse models, as "Renewed" collections reselling and rental systems. Validate the framework proposed	Switzerland	1899
Mud Jeans ***(7)***	1	Fashion Brand	Fully circular, sustainable and fair-trade certified denim brand, using recycled jeans, circular design and rental principles to supply high quality jeans. Leading the way for sustainable development with a strong brand equity.	Deepen the foundation for the case study used in the testing of the framework. Assess the validity and quality of recycled fibres. Investigate the potential of rental systems.	Holland	2012
Luxury brand X ***(8)***	1	Fashion Brand	Major Italian fashion luxury brand. Avant-garde style merged with fresh sustainable developments.	Assess fashion supply chain current state and key sustainable growth directions. Assess the validity and quality of recycled fibres, as well as repair and resale systems	Italy	1920s
RETE ONU ***(9)***	2	Collector, Sorter	Humanitarian organisation for the international cooperation, collecting used clothes and supporting charity projects, by reselling in second-hand Humana shops or exporting to less developed countries.	Assess collectors' subsistence hurdles and inefficiencies. Gather relative economic data. Validate the proposed framework	Italy	1998
CENTROCOT Spa ***(10)***	1	Testing & Certificates	Provider of technical activities such as laboratory tests, research & development, technical support, experimentation and formation. Partner of the Europe Life M3P project for the development of a functional by-product exchange platform.	Investigate performances of recycled fibres and issues related to the use of post-consumer waste. Assess the potential of online by-products sharing platforms.	Italy	1987
Evrnu ***(11)***	1	Recycler	Textile innovation B-certified company, developer of NuCycl technology which recycles cellulosic clothing waste into new fibres. Garment-to-garment recycling in collaboration with notable brands as Adidas and Stella McCartney	Assess potential and stumbling blocks of chemical recycling.	Seattle, US	2014

Chemical Recycler X ***(12)***	1	Recycler	Chemical recycling technology developer, decontaminating and extracting both polyester polymers and cellulose from cotton, non-reusable textiles and PET bottles and packaging. Partner of many noteworthy fashion stakeholders. Reference for the fully closed-loop development of textiles which cannot be reused.	Assess potential and stumbling blocks of chemical recycling. Explore market development requirements and collaborative structures with other reverse supply chain actors.	United Kingdom	2005
Renewcell ***(13)***	1	Recycler	Chemical recycling technology developer, dissolving cotton and other natural fibres into a new, biodegradable raw materials, branded as Circulose Pulp. Part of the European Life program.	Assess potential and stumbling blocks of chemical recycling.	Sweden	2012
Circle Economy/ Fibersort ***(14)***	1	Consulting firm/ Sorter	Not-for-profit impact organisation, supporting businesses, cities and governments and empowering a global community to create the conditions for systemic transformation. Among manifold sustainability projects they developed disrupting automatic NIR sorting technology Fibersort.	Assess fashion supply chain current state and key sustainable growth directions. Assess market potential and implementation requirements of NIR sorting technologies	Netherlands	2008

Table. 1 - Characterisation of firms interviewed with related investigation objectives

Basically, table x shows how the chosen sample entails a heterogeneous combination of more or less 'sustainability champions', made up of both incumbents and various start-ups, thus offering a great variety of forehand data about innovation frontiers, operational hurdles and strategic directions. Regular questions proposed in each interview regarded fashion industry strategic prospects; circular economy potential, drivers, barriers; enhanced collaboration requirements; potential of blockchain, sorting and recycling technologies; potential effectiveness of product stewardships schemes. Accordingly, a sample questionnaire will be provided in Annex I. Beyond this, specific goals (as shown in table x) are designated for each interview, in respect to type of firm, products and business models in place.

The kaleidoscope of insights gathered from the interviews was then mixed up with secondary information in order to extract serviceable conclusions and build the foundation as well as the testing and validation for the developed framework.

Model development process

Specifically, the novel output of the dissertation is a theoretical model, alongside the relative practical implementation guidelines and testing outcomes, proposed as solution of aforementioned issues and current state lacunas. The gaps found in the literature review constitute the foundation of the model itself, i.e. they represent the first roadmap laid down over which further work aims at delineating which matters are possible to be solved, which minimized and which will remain open to further investigation. In particular, the chapters mostly tapped by the framework relate to:

- 'Waste creation: current state' (See **Section 1.1.4**.)
- 'Business-As-Usual scenario: EBIT decline' (See **Section 1.1.5**.)
- 'Waste hierarchy' (See **Section 1.2.2**.)
- 'Circular barriers' (See **Section 1.2.4**.)
- 'Circular business models for the fashion industry' (See **Section 1.2.5**.)
- 'Industry 4.0 and blockchain technology for circularity' (See **Section 1.2.7**.)
- 'Textile reuse and recycling' (See **Section 1.2.8.**)
- 'Reverse logistics' (See **Section 1.3.2**.)
- 'Extended producer responsibility' (See **Section 1.3.3**.)
- 'Market failures analysis' (See **Section 1.3.3.1**.)
- 'EPR limits' (See **Section 1.3.3.3**.)
- 'Potential solutions' (See **Section 1.3.3.5**.).

In these regards, the interview outputs of primary information were exploited during all phases of the conception process. Some interviews have been performed at the very beginning of the dissertation research, aiming at the definition of concrete industry requirements, stumbling blocks and opportunities. As the framework would start gaining a more solid form, interviews were used to evolve details for the ease and effectiveness in the implementation of the model. Finally, approaching the end of the dissertation elaboration, interviews represented tests for the validity and potential utility of the framework.

Summing up, the model development process was characterized by massive reiteration and re-evaluation of features as well as of their combination's significance and support towards the desired objectives.

Testing methodology

Aiming at an alignment with the proposed logic of an indirect impact relation between economic convenience of sustainable circular investments and overall environmental performances improvement, the framework testing ground has been designed accordingly. Hence, the structure will be subdivided in two interconnected sub-tests. Both validation conditions will be assessed in combination with a quantitative case study methodology, in order to permit a precise reconnection of the analysis outcomes to a specific set of data.

The case study is constructed by merging different single firm cases, practically setting up a hypothetical supply chain for a specific product. This integration exercise ex-ante shall afterwards enable a proper evaluation of both single actors as also of integrated value chain effects, explicating the depth of interrelations to consider when designing an incentive regulation.

In particular, the drivers for the selection of the primary product business case will be:

- *Innovativeness of the company business model*
- *Relevance of the product, in terms of diffusion and sustainability impacts*
- *Consciousness and strategic orientation of the company*
- *Availability of quantitative data*
- *Pertinence to the European apparel sector scope of analysis*

As a result, the final choice regarded a classic apparel item which is usually correlated with hazardous environmental impacts and which impacts greatly also economics, since it is a member of almost any wardrobe worldwide: ***jeans***. Aiming at the demonstration of the improvement potential for such a product, the brand selected is a pioneer in its field, thanks to exceptional performances in disruptiveness and sustainability: ***MUD JEANS***, which was already investigated during the interviews. Consistently, the company members state by themselves: "We aim to change the fashion industry, starting with the most popular piece of clothing: a pair of jeans" (MUD Jeans, 2020a), explicating the significance of the probably most low hanging fruit. For the detailed explanation of the business case see **Section 4.1**. Upon this, the other supply chain players, i.e. fibre producer, fabric producer, collector, sorter and recycler, have been selected according to availability of quantitative data, alignment with MUD Jeans strategic perspectives, pertinence to the European apparel sector scope of analysis.

The process of data gathering was based partly on primary information from interviews and partly from secondary data sources, i.e. mainly company financial and sustainability reports, in addition to industry-wide assumptions through web researches. The availability of quantitative primary inputs indeed did not suffice the requirement of standardised categories of data throughout each of the actors and was thus complemented with various economic and technical hypotheses, that will be presented in detail in **Sections 4.2, 4.3.1, 4.4.1**.

Furthermore, both validation studies will be applied to multiple scenarios for each supply chain actor, comparing the business-as-usual case with other three different cases of gradual implementation of the features proposed in the model. The heterogeneity entailed favours indeed different company behaviours, with rising preference in accordance with the waste hierarchy. The separation of scenarios shall permit a more accurate evaluation of the validity of each building block, as will be explained and represented more in depth in **Section 4.2**.

Economic Viability Test

Once the boundaries of the analysis are set, the first test to be carried out is the economic sustainability evaluation of the framework implementation and thus of the building up a specific closed loop system sample. The objective is to demonstrate the negative profitability trend present for Business-As-Usual scenarios and to provide support for the long term business persistence achievable through circular investments encompassed in a diversified product stewardship regulative framework. The expectation to verify refers to the fact that profitability enhancing factors shall exceed additional costs to bear for sustainability-oriented companies. Among the former there will be: gains from reverse supply chain optimisation, increased demand from conscious consumers, creation of new alternative revenue streams, appraisal of discounts on EPR fees, advantages in competitiveness, operational efficiency gains from blockchain utilisation. Among the latter there will be: investments necessary to produce and commercialize eco-designed garments, investments for the initiation of blockchain architecture, fees to be paid for the extended producer responsibility scheme, defeat of traditional business lines, temporary increase in inputs costs. In these regards, EBITDA values magnitude and trends will be studied for each supply chain actor in each proposed scenario.

For what regards the establishment of a new product stewardship policy, as established in various current EPR regulations, the fees to raise from clothing and textile producers shall mirror the net operational costs from collection, sorting and treatment costs of separately collected waste management minus the revenues from recovered material sales (Oecd / European, 2014). In particular, since the framework will represent a combination of traditional EPR logics together with individual firm-level sustainability-oriented actions, in the forms of eco-design, reuse business models and reverse logistics; the logical algorithm used to define taxes, discounts and financial impacts will be the following:

1. *Cover operating costs for end-of-life management (assuming that everything that is produced is destined to pre- and post-consumer waste)*
2. *Define resulting figures net of revenues*
3. *Distribute fees weighting according to firm's waste volumes and supply chain position impacts*
4. *Define discounts for producers according to impacts (volumes) avoided from EOL common management*
5. *Define subsidies in order for EOL actors to have a positive breakeven*
6. *Assess delta NPV of circular investments vs Business-As-Usual for each actor (at different levels of application of the model)*
7. *Assess supply chain effects*

Once all financial flows for each scenario are arranged, at step 6 an approximate Net Present Value analysis will be carried out in order to test the economic predilection for closed-loop scenarios. The yearly projections of earnings net of costs and initial investments will thus be discounted, considering the timely value of money. Finally, the outcomes will represent the preferable scenario strategies for each player.

With the financing of end-of-life management infrastructures and the application of discounts for circular sustainability champions, the foundation is laid for the scaling up and optimisation of the reverse supply chain, facilitating higher convenience of circular production inputs while also incentivising prevention, minimization and reuse of resources throughout industry players. In these circumstances it is plausible to foresee a boost in manifold sustainable-oriented market niches, connected also to enhanced consumer consciousness as well as related buying and caring behaviour. This transition will thus lead to overall diminished waste flows and augmented volumes of materials held in circulation.

The related assumption will need to be verified through a multi-indicator environmental assessment approach. As emerges in **Section 1.2.8**., especially for the fashion ecosystem, there is a critical prerequisite to develop and exploit more accurate and standardised methods for the evaluation of polluting impacts diversity and for proper comparisons among various sourcing, production and disposal alternatives. Indeed, focusing on one single dimension (i.e. resource use) may generally represent a limitation in the assessment of CE models, leaving other important factors, such as emissions and energy use, out of the analysis (Moriguchi, 2007).

The methodological choice will thus consist of a Life Cycle Assessment through the use of the software Simapro. The aim is to define the most impacting supply chain areas and inputs as well as to assess the effect over manifold impact categories: 'Climate change Human Heath', 'Ozone depletion', 'Human toxicity', 'Photochemical oxidant formation', 'Particulate matter formation', 'Ionising radiation', 'Climate change Ecosystems', 'Terrestrial acidification', 'Freshwater eutrophication', 'Terrestrial ecotoxicity', 'Freshwater ecotoxicity', 'Marine ecotoxicity', 'Agricultural land occupation', 'Urban land occupation', 'Natural land transformation', 'Metal depletion', 'Fossil depletion'.

Furthermore, LCA has been preferred over single impact assessment methods, due to the requirement to analyse an extensive diversity of impacts related to the fashion manufacturing system and to the creation of undifferentiated and polluting waste. Such a calculation technique helps to holistically study all phases of production, delivery and recovery of an item across different supply chain actors. Specifically, a cradle-to-cradle approach has been exploited to align with the dissertation objectives to demonstrate the economic and environmental sustainability of a widespread circular adoption. In this sense, the goal would be to verify the magnitude of environmental performances improvement, approximation towards 2030 SDGs defined by the United Nations and respect of earth capacity boundaries; i.e. the benefits related to the diffused application of waste hierarchy principles and closed-loop management

of resources, against business-as-usual stagnation or worsening of performances.

The choice of the software is based upon its global lead and diffusion in over 80 countries, trust by industry and academics as well as validity of its background databases. Specifically, the version used is '8.0.4.30 Analyst', the database chosen is 'Ecoinvent 3 – consequential – unit' and the standard assessment method 'ReCiPe Endpoint (H) V1.11 / Europe ReCiPe H/A'.

In regards to the definition of functional unit, system boundaries (upstream, core and downstream process typologies), allocation rules, data quality requirements and default impact categories, Product Category Rules of the International EPD® System have been followed. Environmental Product Declarations (EPD) are voluntary documents for a company or organisation to present transparent information about the life cycle environmental impact for their goods or services. In turn, a PCR complements the General Programme Instructions and the standards by providing specific rules, requirements and guidelines for developing an EPD for one or more specific product categories, enabling different practitioners using the PCR to generate consistent results when assessing products of the same product category (Product Category Classification, 2019). The system will be thus used to develop a standardised analysis and presentation of results. In particular, for the business case considered, the EPD for 'trousers, shorts and slacks and similar garments' - Product Category Classification: UN CPC 282 - has been employed.

Deepening the procedure deployed within the software, the basic steps for the definition of the modelled business case are the following and are formulated for each of the scenarios analysed:

a) Definition of basic '***process***' of virgin jeans production

b) Definition of adjusted '***process***' of jeans production, adding correlated '***avoided impacts***'

c) Definition of related '***assembly***', encompassing the production process defined at step (b), as also additional upstream transport, spinning and weaving processes

d) Definition of related '***life cycle***', encompassing the assembly defined at step (c), as also additional downstream transport, use processes and a diversified '***waste scenario***', accounting for the variety of end-of-life routes entailed in each case analysed

Specifically, '***processes***' are identified in the database indexes according to their output and can be linked to each other to create networks. Product stages are used to describe the composition of the product, the use phase, and the

disposal route of the product, always referring to diverse processes. Among product stages there are ***'assemblies'*** used to define the product itself and ***'life cycles'*** used to give an end-to-end perspective, linking to assemblies, processes, disposal and waste scenarios or also other life cycles. Finally, ***'waste scenarios'*** are processes that refer to material flows, losing information on how the product is split up in different components (subassemblies), focusing only on single materials included. ('Introduction to LCA with SimaPro Colophon', 2013).

Accordingly, all specific details of the evaluation process will be thoroughly exposed in combination with the description of the case study and relative assumptions, in **Section 4.4.1.**

Section 1

STATE OF THE ART AND PRACTICE

This section aims at providing the state of the art and practice of the diverse insights analysed and exploited as inputs for this dissertation work, tackling a broad scope of topics investigated. The objective is to gain a broader point of view and develop solutions basing on the merging of key strength points of different paradigms. The three broad conception categories will be mirrored in the structure of this review, as shown in figure 2. The analysis will thus first explore in depth concrete fashion current state issues, secondly evaluate the resolution potential of circular economy models as well as related digitalisation technologies and finally explore excess management models in order to make the whole system efficient and design incentives for firms in an effective way.

The illustration of investigated topics will unfold specific improvement gaps that represent the basis for overall research questions and objective to be answered through the development of the model and its implementation testing. In order to reach a correct proposition of solutions, it will be thus reasonable to start from the understanding of issues related to the scope of analysis deployed above.

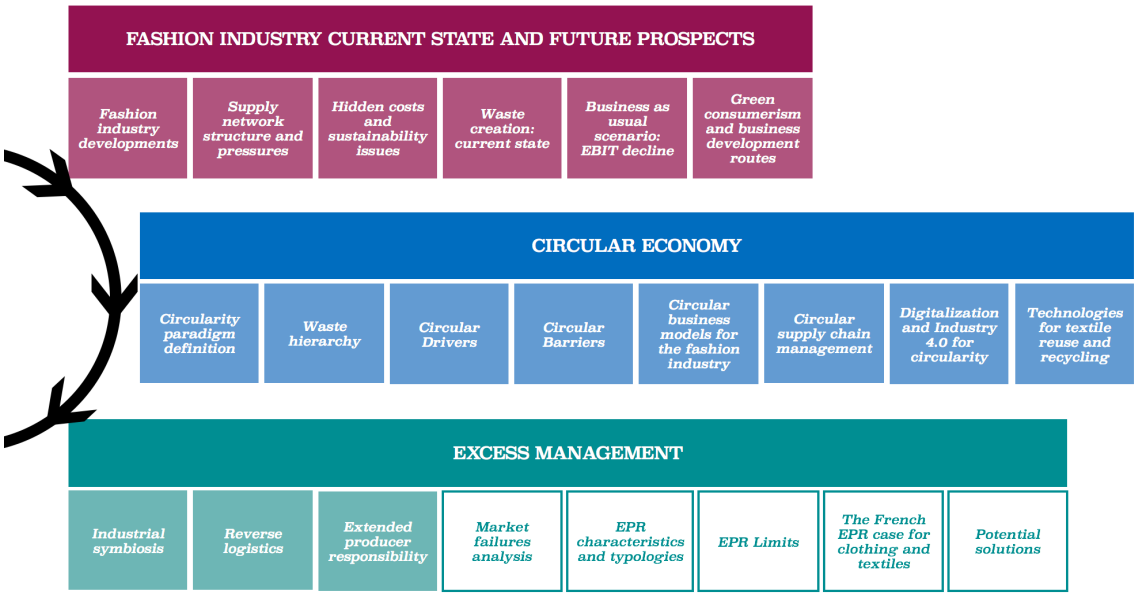


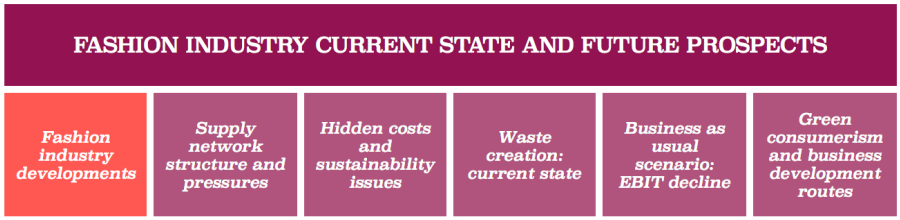
Figure. 2 - State of the art and practice schema

1.1. FASHION INDUSTRY CURRENT STATE AND FUTURE PROSPECTS

Since many decades, fashion has been commonly associated to the concepts of beauty, novelty and creativity. Consumers have been following its "*trends*" as if they would enhance *life satisfaction*, almost completely neglecting the actual socio-economic and environmental macro-trends implied in such a fast-moving production system.

Reality is indeed quite the opposite of the idyll of style which is commercialized. In the last 5 to 10 years, increasing relevance has been given to the topic by all kinds of stakeholders. Among institutions, firms, governments, consumers and scholars there is a movement of disconnection from the type of reflection of culture that popular fashion indicates. Indeed, the executive survey for the "State of Fashion 2020" McKinsey report, evinces a prevailing mood of anxiety and concern among respondents (Beltrami, Kim and Rolkens, 2019). Fashion For Good and the Boston Consulting Group state that since the fashion industry is one of the world's major manufacturing sectors, with a $2 trillion market size, contributing 2-2.5% to global GDP, it also offers vast opportunities for positive disruption. Given its disproportionately large environmental and social footprint, it will play an even bigger role in the efforts to reach the 2030 SDGs defined by the United Nations. Currently, while some fashion companies have already made progress, the industry as a whole has not yet undertaken the degree of systemic change necessary to keep pace with global climate goals, stakeholder demands, and regulatory headwinds (Fashion for Good and Boston Consulting Group, 2020). Furthermore, while the importance of protecting the ecosystem is starting to be well understood, the costs of dealing with waste can be burdensome (Bouton *et al.*, 2016). Generally, as stated by the Global Fashion Agenda and the Boston Consulting Group (Lehmann *et al.*, 2018), the Pulse Score[2], a health measure for the fashion industry, was 38 out of 100 in 2018, showing great hidden costs and great margins for improvement.

[2] The Pulse Score is a global and holistic baseline of the sustainability performance in the fashion sector. It is based on the Sustainable Apparel Coalition's proprietary Higg Index and extends its scope to extrapolate its findings to the entire industry. The Higg Index, developed by the Sustainable Apparel Coalition, is a suite of self-assessment tools that empower brands, retailers, and facilities of all sizes, at every stage of their sustainability journey, to measure their impact on environmental and social dimensions and to identify areas for improvement. (Lehmann *et al.*, 2018)



Given the relevance of the fashion industry within the manufacturing sector and its impact on global GDP as well as on societies development, it is first of all necessary to investigate the historical background and the factors driving the development towards a fast-fashion paradigm and stringent supply chain pressures.

1.1.1. *Fashion industry developments*

Fashion is defined as the *'style and custom prevalent at a given time'* (Merriam-Webster, 2020). The concept may be applied to various contexts but for the sake of this dissertation it will be referred to the apparel sector.

Historically, the global fashion industry officially began its existence with the rise of mass-production in mid-19th century, thanks to the development of the sewing machine, of global capitalism and of factory systems of production (John S.Major, 2020). Whilst prior to that moment most clothing products were custom-made, after that economic boom consumption patterns totally changed. The fashion industry started following a fixed calendar of trade fairs and shows presenting the forthcoming season's trends (Birtwistle, Siddiqui and Fiorito, 2003). This made it possible to forecast demand as long as a year before the time of consumption based on previous sales data (Guercini, 2001). Marketers began to observe an ever-increasing demand, reaching exponential acceleration rates between the late 1990s and the 2010s due to the global advent of the 'fast fashion' framework, originating from the US 'quick response' model of the 1980s (Lowson, King and Hunter, 1999). This system of production is built on an aggressive search for production efficiency, enhanced forecast accuracy due to stricter time frames analysed and strong marketing activities. The aim was and is to attract customers into stores as frequently as possible in order to increase the frequency that they purchase fashionable styles (Barnes and Lea-Greenwood, 2006). Thus, currently, the extreme responsiveness of the industry drives towards a rhythm of proposal of new articles of even twice a week in some cases, mainly through mass markets but actually slightly influencing even luxury segments (Inditex, 2020). Alongside with *time to market, delivery time, offer variety and ceaseless novelty*, *cost* generally strengthened its role as parameter driving the rising competition. In turn, this pushed a relentless amplification of clothing's relative convenience inside the consumption basket, in spite of the continuous inflation present in all other sectors in worldwide economies (as shown in Figures 3 and 4).

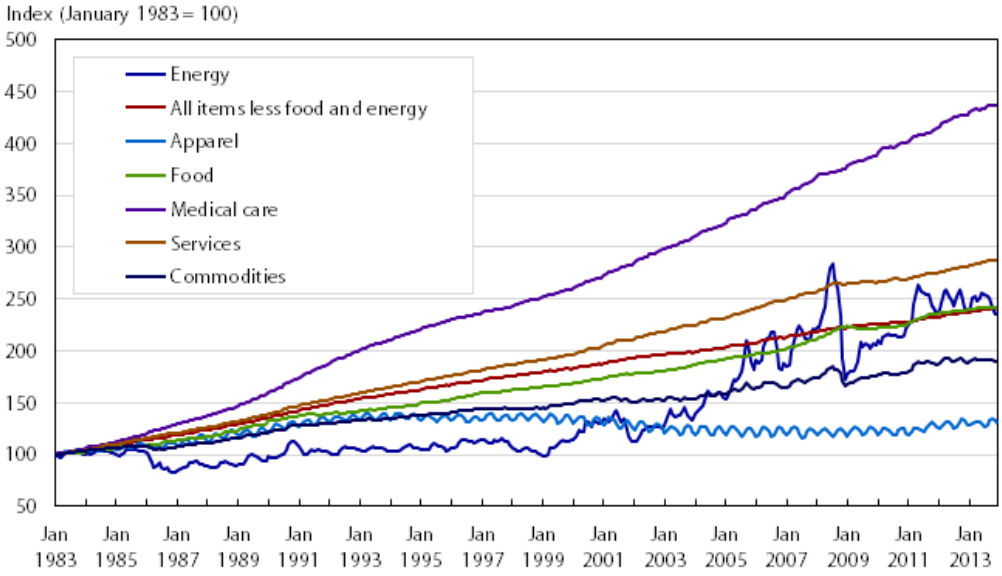


Figure. 3 - Selected Consumer Price Index series, 1983-2013 (Reed, 2014)

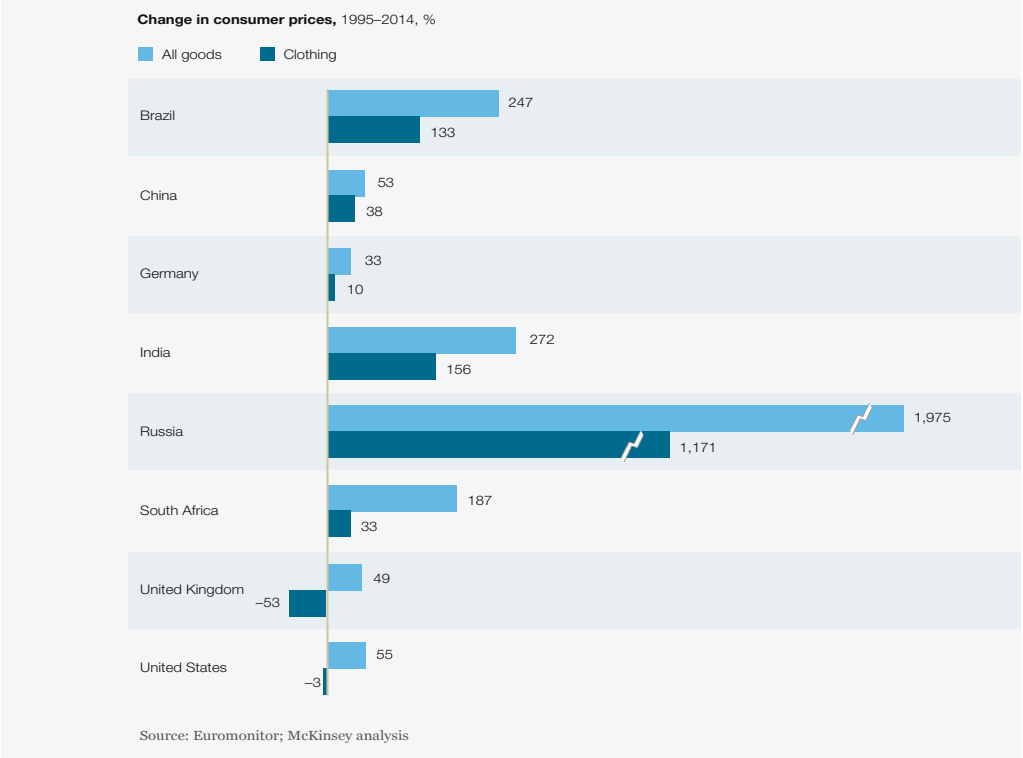


Figure. 4 - The slow rise in clothing prices, compared with other consumer goods has made clothing more affordable (Bouton et al., 2016)

For what regards Europe for example, the European Parliamentary Research Service states that according to EEA estimates, between 1996 and 2012 the price of clothing increased by 3 %, but consumer prices in general rose by about 60 %. This meant that, relative to the EU consumer consumption basket, the price of clothing fell by 36 % (European Parliament, 2019). Intrinsically, this drop also represented the consequence of false incentives towards increasing consumption and unsustainable production. The share of clothing in household consumption stood largely the same: it was 5 % in 1995 and 4 % in 2017 (Mourelatou, 2020), likely demonstrating the growing need to own larger volumes of goods.

Accordingly, consumers began considering clothing, shoes and accessories as disposable goods, following the economic imperative of "Spend now, think later", buying without reasoning and dramatically lowering the rates of clothing utilization by 36% in 15 years (as shown in figure 5) (Foundation, 2017). McKinsey asserts that from 2000 to 2014 the number of garments purchased each year by an average consumer increased by 60 percent. Additionally, across nearly every apparel category, consumers keep clothing items about half as long as they did 15 years before (Bouton et al., 2016). European data follow the trend but are characterised by a smaller magnitude: between 1996 and 2012, the amount of clothes bought per person in the EU increased in fact by 40 % (Mourelatou, 2020). The accelerated obsolescence rates were measured with more than 30 % of clothes in Europeans' wardrobes that have not been used for at least a year (Remy, Speelman and Swartz, 2016).

Generally, the trend continues, as global demand for textile products follows and will likely keep following a steady growth, even more than the one of global GDP (Oerlikon, 2015). Only in the last year, forecasts tend to slow down a little to an expected growth of 3 to 4 percent in 2020, slightly under the levels of 3,5 to 4,5 in 2019 and 4 to 5 in 2018 (Beltrami, Kim and Rolkens, 2019).

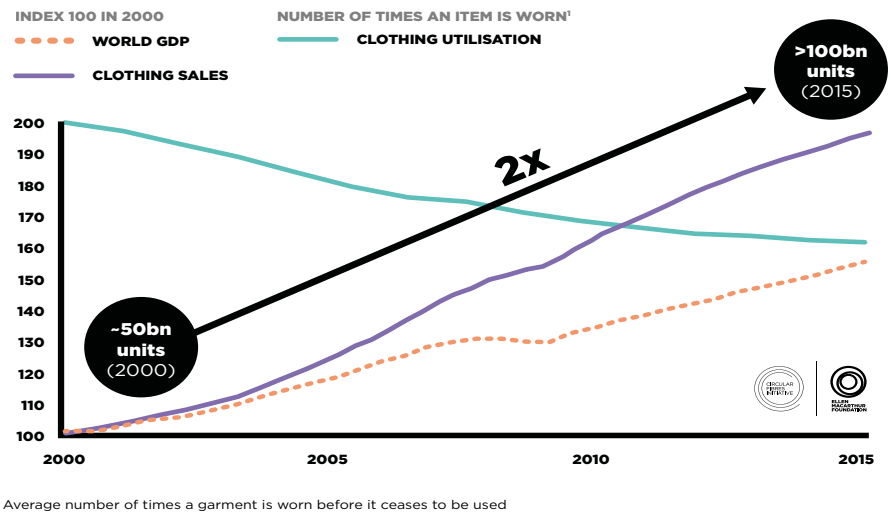
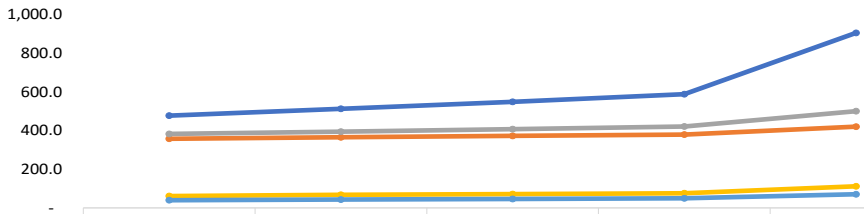


Figure. 5 - Growth of clothing sales and decline in clothing utilisation since 2000 (Foundation, 2017)

At this point, the 'Fast fashion' movement and the evolution of consumption patterns worldwide shall be considered jointly with the diverse macro-trends of incessant economic development, population growth and globalization of markets to visualize the whole picture.

The *increasing number of inhabitants* is an especially determinant boosting factor since it is mainly distributed in developing countries where it combines with a trend of rising social role of middle classes, which expand their market power and thus enlarge consumption exponentially. McKinsey asserts that economic expansion is happening across Asia (as shown in figure 6), especially observing India take centre stage in 2019. The Indian middle class is further forecasted to expand at 19.4 percent a year over the same period, outpacing China, Mexico and Brazil (Amed *et al.*, 2018). Furthermore, demand is being driven by digitally native consumers, excited by the possibility of creativity and self-expression (Beltrami, Kim and Rolkens, 2019).



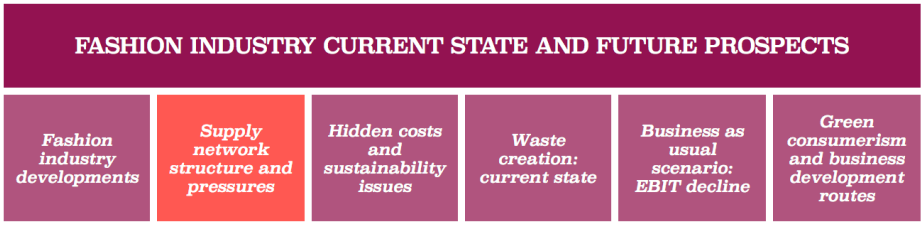
	2016	2017	2018	2019	2024
Asia Pacific	478.0	513.5	549.5	589.0	906.3
North America	358.5	365.8	373.1	380.0	420.8
Europe	383.2	395.0	408.1	421.9	501.1
South America	61.7	68.2	71.9	76.3	112.2
Rest of the World	40.3	43.3	46.4	49.8	70.9

Asia Pacific North America Europe South America Rest of the World

Figure. 6 - Global Apparel Market Size Numbers (Fibre2Fashion, 2019b)

On the other hand, *globalization* impacts not only the expansion of developing economies and the general lowering of prices connected to free trade, but also the structure of supply chains and the related different performance dimensions. Consequently, the production of textiles and clothing has now one of the most complex global value chains, with most products on the internal EU market manufactured outside the EU, often in countries with lower labour and environmental standards (Binder, 2016). This represents the negative chain reaction caused by globalised corporations, since the split-up and diffusion of manufacturing and processing activities, especially in less developed nations, induces an unmanageable loss of transparency and an exaggerate exploitation of resources and workers.

Finally, following a vicious cycle, the increase in complexity of fashion supply chains in combination with uplifting demand entails the potential for ever more detrimental effects on the society and the environment



If the previous chapter explored the macroeconomic trends impacting the fashion industry development, it is now necessary to switch to a meso-level of analysis and investigate questions regarding the strains and drivers pushing towards extreme supply chain efficiency, flexibility and speed.

1.1.2. *Supply network structure and pressures*

During the last decades, competition evolved basing more and more on supply chain design and management instead of on products. In connection to the 'fast fashion' revolution, the industry has a highly competitive structure that not only puts pressure on costs, but also the ability to offer the "newest" possible trend to the customers (Turker and Altuntas, 2014).

The geo-strategic decision making for each manufacturing step became a game changing factor, since companies increasingly optimised their networks by managing the most value-adding activities in locations with a high level of control and low distance, whereas offshoring less differentiating processes. According to MacCarthy and Jayarathne, in the last 30 years, textiles manufacturing has shifted significantly to less developed countries (MacCarthy and Jayarathne, 2013).

On one hand, the large dispersion of the value chain relating to the need to sell worldwide to improve brand positioning also enhanced the requirement of manifold intermediation. On the other, market rivalry was expressed through an increasing trend of horizontal aggregation of firms in the retail stage in order to create giant holdings of multi-coloured brands, taking advantage of operational, financial and marketing synergies. As McKinsey states, polarisation persists and the "Super Winners" — the top 20 players by economic profit — account for more than the combined economic profit of the entire industry, propelling a "winner takes all" market with troubling implications for laggards (Beltrami, Kim and Rolkens, 2019).

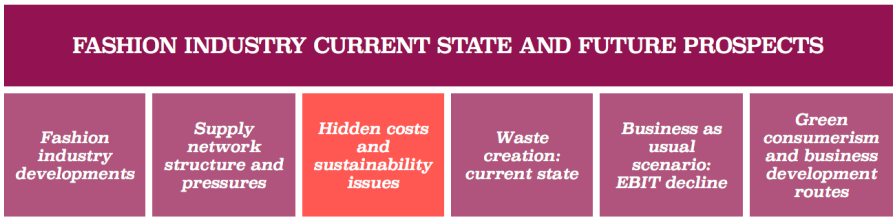
Still, Eurostat data show that in the traditional manufacture-textile sectors, 86% of the companies have less than 10 employees (i.e., micro-enterprises) and only 0.4% of them have more than 250 employees (Eurostat, 2020). Thus the resulting structure remains very fragmented, SME-dominated and multi-layered. Such a quest towards efficiency from the firm perspective actually shows off large welfare losses, especially in the fashion context, since mark-

ups are extremely enlarged. This is due to the combination of aforementioned factors, such as: the great number of intermediaries distorting market conditions (Reverse Resources, 2017), the differentiation of market power levels depending on holding and supply chain position, the key role of the design stage in influencing both upstream and downstream actors. These price distortions further worsen the issues linked to having such relatively low prices. The high standard of mark-up pricing pushes indeed to fully exploit the diversity of economic conditions among different countries searching for low wages and less strict laws, finally inducing even further fragmentation of the supply chain in order to locate each activity in the economically best option. The consequences lie in higher social costs for purchasing products characterized by much lower quality of inputs and processes and worse human conditions than what would be necessary with a more linear and transparent supply network. Similarly, also increased time pressures on the order cycles of the fast fashion industry result in employee abuse and other unethical working practices at manufacturing sites (Barnes and Lea-Greenwood, 2006).

Lastly, the evolution of this trend is mixed with other strain drivers which may actually leave space for innovation and sustainable development in order to solve ultimate challenges. According to BCG, the main supply chain pressures are (Abtan, Bellaiche and Vahle, 2013):

- Globalization demands balance between global consistency and local needs
- Digital movement bringing about greater price transparency, increasing the potential for product refreshment, and adding pressure on margins—all of which have key implications on supply chain flexibility.
- Demand for "omni-channel" offerings, pulling new supply chain modes as delivery from the store, in-store pickup, and exclusive collections.
- Financial crisis boosts economic volatility which requires higher operational flexibility

Hence, supply chain requirements were and are to be at the same time "fast, flexible and lean" (Abtan, Bellaiche and Vahle, 2013). Bruce and Daly (2006) argue that even established supplier-buyer relations in the fast fashion industry should have a short-response nature in order to apply both lean and agile supply chain strategies, while their internal functions should be integrated in order to expedite a smooth buying process (Bruce, Daly and Towers, 2004). In particular, the short lead times demanded by consumers become extremely stricter: in 2018, customers of Amazon in the US expected deliveries within 24 hours, as opposed to a 9-day delivery time expectation in 1995 (Amed *et al.*, 2018). However, in order to become and stay responsive, various ethical, employment (de Brito, Carbone and Blanquart, 2008) and environmental issues are being disregarded, which is creating an unsustainable sectoral structure (Turker and Altuntas, 2014).



Accordingly, such strict fast-fashion oriented prerequisites for supply chain performances come at a cost for the whole surrounding eco-system. The upcoming chapter shall thus assess the factors causing the creation of huge negative externalities, dislocating the market equilibrium away from the preferable condition of Pareto efficiency.

1.1.3. *Hidden costs and sustainability issues*

As already mentioned, what emerges is that today's linear clothing system leaves economic opportunities untapped, puts pressure on resources, pollutes the environment and creates negative societal impacts at local, regional, and global scales (Foundation, 2017; Lehmann *et al.*, 2018). It is becoming extensively understood that earth limited resources won't keep up the pace of human consumption and production patterns. Moreover, the boundaries of raw materials provision are being overstretched because of environmental degradation impacts, such as: resources depletion, terrestrial disturbance, soil over-exploitation, global climate changes, ocean acidification, ocean warming, freshwater over-exploitation, freshwater eutrophication.

Beyond these supply limitations, demand for raw materials (mostly non-renewable) for global clothing production keeps accelerating, as it set at 98 million tons in 2017 and is expected to triple by 2050 (Foundation, 2017). Against these growing needs, competition for land usage strengthens, causing macroeconomic imbalances. For instance, a deficit of five million tonnes for cotton is predicted already for 2020, pushing global denim jeans brand Levi's® to identify cotton as the most significant risk within its 2030 fibre strategy (Girn et al., 2019). In addition, this demonstrates not only how the current production methods are environmentally unsustainable but also how not resilient they are against the rapidly changing climate, ultimately undermining the industry's ability to maintain future production.

Generally, according to the Autex Research Journal, the limits of the present linear economy model (take-make-waste) are extremely apparent when examining the textile and clothing industry (Koszewska, 2018).

The most important third party institutions depict in numbers the gravity of the current state, being the fashion system the second most polluting industry worldwide (Quantis, 2018). The Ellen MacArthur foundation states that in 2015 greenhouse gas (GHG) emissions from textiles production totalled 1.2 billion

tonnes of CO2 equivalent (Foundation, 2017). Accordingly, the Pulse report measured 3990 million metric tons CO_2 eq in 2016, posing the apparel and footwear industry impacts at 8,1% of the global cross-sector estimation of totally 49300 million metric tons CO_2 eq, given also the influence on sectors as agriculture, transportation, energy generation and petrochemical industry (Lehmann et al., 2018). For what regards Europe, clothing accounts for between 2 % and 10 % of the environmental impact of EU consumption (European Parliament, 2019).

In order to analyse the sophistication and magnitude of the different factors that sum up into the abovementioned aggregate figures, arguments shall diversify according to supply chain stages. Generally, it should also be considered that one of the largest issues stays in the fact that the principles of economic convenience drive production choices and mostly worsen sustainability issues. This is evident especially in the textile industry, since the fibre market is dominated by unsustainable alternatives and greener options are barely holding up their niches.

Thus, the first step to be studied shall be the production of raw materials which is responsible for a large share of the environmental impact of the textile and clothing industry, not least from growing crops for natural fibres (European Parliament, 2019). According to VF, the environmental impacts attributed to materials account for approximately forty-two percent of their total environmental footprint (VF, 2018).

Generally, sixty-three percent of textile fibres are derived from petrochemicals (Lenzing Group, 2017) whose production and fate give rise to considerable carbon dioxide (CO2) emissions (Shen, Worrell and Patel, 2010). The remaining 37% is dominated by cotton (24%), a thirsty plant associated with water depletion - the desiccation of the Aral Sea being the most infamous example (Micklin, 2007) - and toxic pollution, due to intensive use of pesticides (FAO-ICAC, 2015).

In regards to the extreme pressure on earth boundaries, it is expected that demand for alternative products will rise significantly. As shown in a Textile Exchange report, the share of sustainable cotton increased from 6 % in 2012 to 2013 to 19 % in 2016 to 2017 (Textile Exchange, 2017). Consistently, 36 of the world's most renowned clothing and textile companies have already pledged to use 100% sustainable cotton by 2025 (Fibre2Fashion, 2019a). Additionally, the industry is also testing less frequently used natural fibres, such as hemp, flax, linen and nettle, that require less water, fertilizers and pesticides (Kerr and Landry, 2017). Furthermore also fabrics produced through fibre to fibre (F2F) reprocessing of post-consumer textiles may offer environmental benefits as reduced water consumption among the other(Girn *et al.*, 2019).

Thus, it is evident how the ability in setting conscious principles for the selection of fibres and extraction process requirements will become an increasingly critical core competence, on which companies may or may not

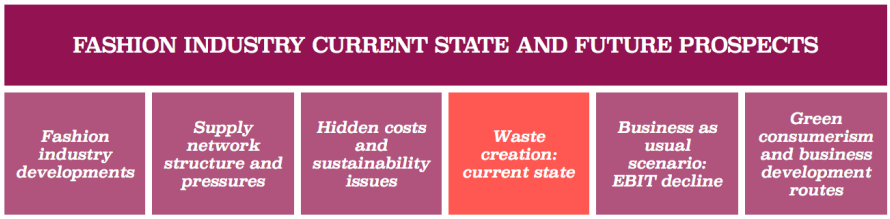
built a differentiating factor, depending on the foresight of their long term strategies.

Further on, wide attention must be given also to the design and management of textile processing techniques. For most categories of environmental impacts, later stages in the textile production process may indeed give rise to even larger effects, depending on the dyeing and finishing options selected (Roos *et al.*, 2015). According to the EMA foundation for every kilogram of fabric, an estimated 0.58kg of various chemicals are used. For instance, for what regards the production of 1kg of cotton textiles, 0.35–1.5kg of chemicals will be necessary in the process (Foundation, 2017).

Considering the transportation necessary between each actor in the supply network, one must be aware that most textile raw materials and final products are imported into the EU from origins usually comprising long delivery routes, but it is also important to define the relevance of the matter. According to the Pulse of the Fashion Industry report, this stage accounts for only 2 % of the climate-change impacts of the industry, as most players have optimized the flow of goods (Kerr and Landry, 2017). Thus, remarks may be carried out regarding the inherent issues of a high complexity in supply chain structure, but for what regards environmental sustainability attention shall be drawn towards problem solving in the cases where there is greater improvement margin.

In respect to this, there is extensive consensus in the academic world to raise awareness about the implementation of life cycle perspectives instead of limiting strategic decision making based on the make phase considerations. In fact, scanning the whole lifetime of a product, many researchers pose the worst environmental impacts in the use stage, due to use habits, treatment practices and quick obsolescence rates. Taking into account European parameters: the carbon footprint of clothing consumed in one year, 2015, in the EU was 195 million tonnes CO2e. The use phase is shown to have the largest carbon impact for the EU as a whole, although production also accounts for nearly a third of CO2e emissions (ECAP, 2017). On global average, McKinsey estimates that washing and drying 1 kilogram of clothing over its entire life cycle, using typical methods, creates 11 kilograms of greenhouse gases - an amount that companies could reduce by altering fabrics and clothing designs (Bouton et al., 2016).

Furthermore, beyond the necessity for deeper consumers' education regarding the use phase, major care shall also be given to the end-of-life alternatives and treatments to favour. For instance, planned obsolescence represents one of the main obstacles on the way to product durability. Hence, major issues lie systematically within the industry framework commonly adopted.



The previous chapter started analysing the environmental pollution externalities involved with an over-productive fashion system. In turn, the following chapter will inspect the more specific type of externality of waste creation, which builds up enormous volumes of textiles which may still entail great value and which will usually occupy landfill space for hundreds of years.

1.1.4. *Waste creation: current state*

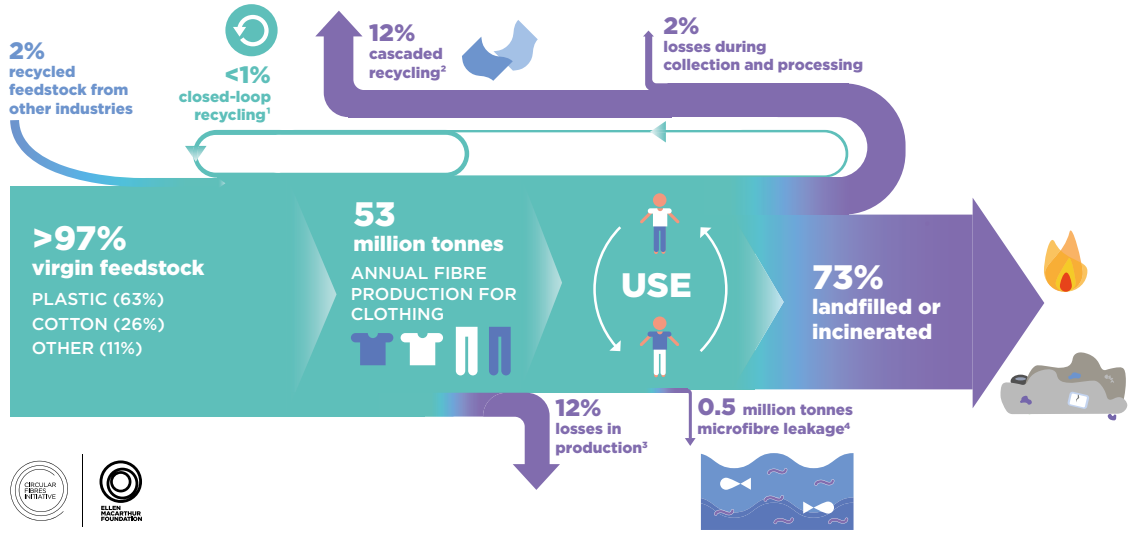
Besides the substantial negative externalities of production processes, clothing and footwear brands in combination with careless behaviours of consumers also cause tremendous amounts of waste, that increment the overall unfavourable environmental complications. Under accusation there are an estimated 92 million tons of textile waste created annually from the fashion industry, namely the equivalent of one garbage truck of textiles landfilled or burned every second, according to the Ellen MacArthur Foundation (Foundation, 2017). In addition to solid waste production, nearly 20% of global waste water is produced by the fashion industry. (United Nations, 2018).

Generally, in terms of material weight, textiles waste is relatively small if compared to other waste streams, but it has a projected large impact on human health and environment, also because its rate is increasing due to the 'fast fashion' model (Bukhari, Carrasco-Gallego and Ponce-Cueto, 2018). Most of the managerial side of the problem comes from the matter in terms of volume, since garments need large spaces to be placed or processed. As the business-as-usual scenario moves on, the issue will become less and less controllable. In its most recent report, the Global Fashion Agenda and The Boston Consulting Group predicts that if the current level of solid waste generated by production processes and end-of-use continues into the future, the fashion industry's waste will increase from 2015 to 2030 by about 60%, as a result of additional 57 million tons of waste being generated annually. Consequently, the total level of fashion waste will rise to 148 million tons by 2030, which amounts to 17.5 kg per capita annually across the planet. (Lehmann et al., 2018).

Much of the problem lay till now in the almost absence of solutions as well as interest in finding them. For instance, economic advantages led companies to keep up their tendencies of over-supply of fashion goods. On the one side, there was no strong demand for efficiency in waste management processes; on the other there were no valuable, not effective nor efficient alternatives to recover

and reuse the resources spread around the globe. Only in the last years there has been some progress in this direction. Technologies, barriers and drivers for this development path will be deepened in the subsequent **Sections 1.2.3. – 1.2.4. – 1.2.8**.

Currently, the state of the products' flows through the value chain, considering one year of production and consumption, is summarized in figure 7.



1 Recycling of clothing into the same or similar quality applications
2 Recycling of clothing into other, lower-value applications such as insulation material, wiping cloths, or mattress stuffing
3 Includes factory offcuts and overstock liquidation
4 Plastic microfibres shed through the washing of all textiles released into the ocean

Figure. 7 - Global material flows for clothing in 2015 (Foundation, 2017)

Clearly, the most apparent figures reflect the linear nature of the system, displaying >97% of input deriving from virgin feedstock and 73% of finished product outputs drastically ending their life cycle through landfilling or incineration. Still, the most emblematic statistic refers to the almost absence of closed-loop recycling, on which academic, regulative and managerial efforts shall be focused and on which this dissertation tries to induce a resolution. Specifically, 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 (Foundation, 2017). On the other side, a relevant business may originate from the use phase since for example UK shoppers are estimated to own $46,7 billions of unworn clothing (BusinessVibes, 2015). Theses streams of unexploited worth actually form the basis for a business case on recycling and reuse models that will be deepened in **Sections 1.2.5. – 1.2.8**. In the same sense, also companies are starting to sight new profit and market creation opportunities as in VF where textile excesses are considered lost resources in which huge value still exists, accounting for more than $500 billions of worth that is not exploited every year due to clothing underutilization and lack of recycling (VF, 2018).

Further on, across the industry only 13% of the total material input is in some way recycled after clothing use (see Figure x). Most of this recycling consists of cascading to other industries and use in lower-value applications, for example, insulation material, wiping cloths, and mattress stuffing – all of which are currently difficult to recapture and therefore likely constitute the final use (Foundation, 2017). Thus, the system is currently able to grant only one more cycle to the life time of specific resources, which yields very negligible improvements for the overall sustainability performances.

The factors that create such a structural state can be classified according to: capacity/supply levels, material flows transparency & traceability, systems design, layout and management.

Primarily, there is an issue of overproduction: the present fashion market framework pushes brands and retailers to offer a range of anything the consumer could desire, introducing new collections in the stores twice a week, widening their variety and offering beliefs of fullness, richness and satisfaction. The outcome of this lavish culture is an enormous quantity of products being held in regular selling conditions for a very short time and then being replaced by new items. In global terms surplus stock is estimated as much as 30% of overall production, remaining blocked in the form of sample stocks, unsold batches or returned items. Yet another 30% only leaves the shops with discount (Ben *et al.*, 2010; Matevosyan, 2016).

Besides these unsustainable output targets, the production process is by itself an intrinsically large source of waste.

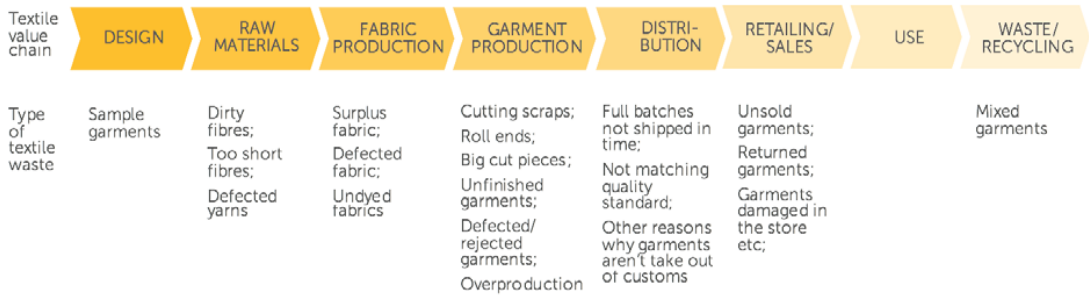


Figure. 8 - Simplified value chain and examples of spill from each phase (Reverse Resources, 2017)

Although there have been actual endeavours to lean up manufacturing steps through process optimisation and pull manufacturing methods, Reverse Resources esteems that there are still >25% of resources that for a variety of reasons are spilled out of original supply chains. (Reverse Resources, 2017) A major question is data transparency and traceability, especially for the production sites in developing countries, which cover the majority of suppliers for the fashion industry. Predominantly, it appears that there is still no urgency

to collect information about productivity, namely at least measures for the comparison of volumes of sellable products against inefficient excesses.

The analysis of both scientific and grey literature displays indeed a wide variety of estimations, inducing uncertainty regarding the data quality. The Ellen MacArthur Foundation considers a total 12%[3] losses in production, including factory offcuts and overstock liquidation, in 2015 (Foundation, 2017). Other previous studies agree on percentages of pre-consumer textiles waste being equal to 10-20% of the textiles used in clothing manufacturing, with superior levels present in less developed economies. Conversely, the report published by Reverse Resources in August 2017 investigates the assessment accuracy of such measures and reveals a critical issue about systematic underreporting (Reverse Resources, 2017).

Beyond all that, as Ann Runnel *et al.* (2017) enlighten, a crucial implication of this lack of transparency is to create fertile grounds for the development of an excessive aftermarket for leftovers, removing any incentives to enable traceability in these "secondary" supply chains. The excess fabrics usually move through 3-5 levels of different traders before reaching next production. This extensive number of intermediaries brings up the market prices, lowers lead times for recycled materials, holds back the spread of knowledge on best practices and limits the percentage of leftovers reaching optimum new life-cycles. Moreover, as a result, factories are unaware which materials are worth segregating from production leading to unnecessary quantities of leftovers which get mixed up in bulk on the production floor, thus losing most of their economic value instantly. (Reverse Resources, 2017)

Still, these production by-products volumes are just moderate fractions of the magnitude of the waste generated in the post-consumer phase and then committed to low value final stops. As mentioned, the Ellen MacArthur foundation estimates in fact that 73% of all resources introduced in the clothing system will be incinerated or landfilled after use steps, requiring a long time to degrade and releasing methane at the same time (Foundation, 2017).

In this regards, there are several issues of discussion emerging. The most impacting determinants relate to the wrong habits and consumptions patterns of end customers, but there are also large technical and systematic knots to be untied, as will be deepened in **Sections 1.2.4 – 1.2.8**. For instance, technologies that would enable clothes to be recycled into virgin fibres are still inadequate. This is why currently most clothes are recycled mechanically, i.e. they are cut up and shredded, which means that the fibres are shorter, decline in quality and lose 75 % of their value. Technologies for chemical recycling that produce virgin fibres of a high quality are available for viscose, polyester and nylon

[3] All percentages are computed on the total volume of inputs necessary for clothing production

and are slowly becoming available, but are not yet fully economically viable, for cotton and blends (European Parliament, 2019).

Aside from this, a critical hurdle that should be analysed and solved at first is identified with the current ineffectiveness of end-of-life recollection systems.

Various sources provide indeed analogue data about the distribution of flows at the end of the traditional supply chain. Only 15-20% of clothing waste is collected globally for reuse or recycling. The remaining 75- 80% is landfilled or incinerated, often within one year of being made, resulting in a great loss of energy and raw materials (Blackburn, 2016; Danigelis, 2017).

Thus generally, the recollection potential is by far unexplored, as it is estimated that the material recovery rate of the post-consumer textiles can reach 90%, 50% of which can be directly reused (Bukhari, Carrasco-Gallego and Ponce-Cueto, 2018). Anyway, the problem actually stays in the flows management afterwards. The Textile Recycling Association and the Ellen Mac Arthur Foundation add that even though some countries have high collection rates for reuse and recycling, much of the collected clothing is exported to countries with no collection infrastructure of their own (OUVERTES Project, 2005). The United States ($575,5 million) and Italy ($118,6 million) are among the leading exporters of used clothing globally whereas African nations like Uganda ($72,3 million) and a few Asian nations like Pakistan ($239,5 million) are among the leading importers of second-hand clothing (Fibre2Fashion, 2019b). In this regards, many African countries are even considering banning the import of used textiles to encourage a competitive textiles industry locally and internationally. (Bukhari, Carrasco-Gallego and Ponce-Cueto, 2018)

This causes a problem of 'geographical burden shifting', since not only the products shipped worldwide result in additional negative impacts through transportation, they usually also definitely loose traceability and more relevantly they meet over-saturated markets, where some resources may be reused but where they prevalently get dispersed either in landfills or even in the environment, due to the low level of development of such countries' facilities.

Finally, to summarize, the current state of the fashion industry faces diversified drawbacks and stumbling blocks. The reasons lie in the low diffusion of effective business models, sustainable supply chain management systems and enabling technologies till current date. The question now is about the progress directions that industry stakeholders will be willing to fulfil in the next decisive years.

Estimates from the Ellen Mac Arthur Foundation warn that if the industry continues on its current path, by 2050, it could use more than 26% of the carbon budget associated with a 2°C pathway. Moving away from the current linear and wasteful textiles system is therefore crucial to keeping within reach the

2°C average global warming limit (Foundation, 2017). To worsen the perspectives, as shown in figure x, a McKinsey report specifies that if 80 percent of the population in emerging economies achieves by 2025 the same clothing-consumption level as the Western world, and the apparel industry will not become more environmentally efficient; the industry's environmental footprint will grow much stronger than what is did (Remy, Speelman and Swartz, 2016).

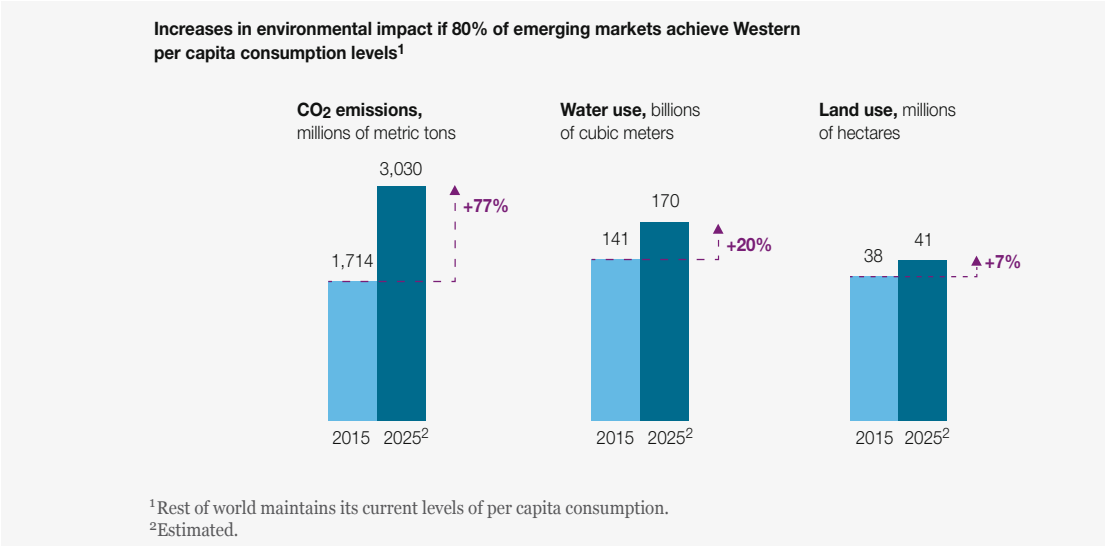
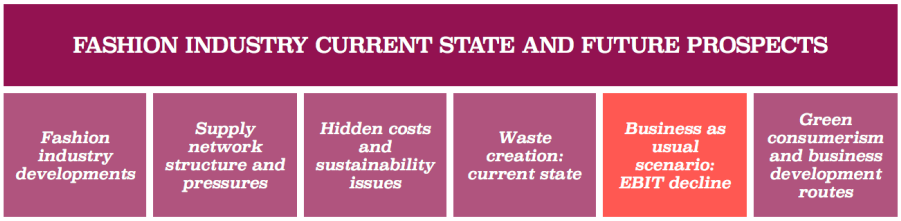


Figure. 9 - As consumer spending increases, especially in emerging economies, the clothing industry's environmental impact could expand greatly (Bouton et al., 2016)



The environmental impacts described in the last two chapters evolve into ceaselessly decreasing long term persistence of economic structures. In these regards, the following chapter tries to respond to the need of quantifying financial and strategic risks, aiming at the automatic transition of companies towards more circular and sustainable business models, once guided by a positive business case alternative to the business-as-usual scenario.

1.1.5. Business-As-Usual scenario: EBIT decline

In order to manifest the gravity of the current state and the enclosed restraint on long term success, the Pulse of the fashion industry report even provides a quantitative analysis about the economic outcomes of the aforementioned negative tendencies of the industry. Projections point out that, by 2030, fashion brands would see a decline in earnings before interest and tax (EBIT) margins of more than three percentage points, if they were to continue business as usual. This would translate into a profit reduction of approximately EUR 45 billion (USD 52 billion) for the industry. (Lehmann et al., 2018)

This entails a series of risks and profit losses, generally relating to the following categories:

- *Reputational risks, due to digitally-enhanced customers and stakeholders*
- *Rising non-renewable raw materials prices*
- *Higher exposure to supply chain shocks*
- *Stricter and more expensive regulatory schemes*

More and more businesses feel indeed already compressed between rising as also less predictable prices in resource markets on the one hand and high competition in end markets on the other (Ellen MacArthur Foundation, 2015). Supply disruptions have the potential to occur via two distinct mechanisms: actual physical scarcity of a raw material or short-term shortages caused by rapid demand intensification, political unrest and instability, natural disasters, etc. (Alonso *et al.*, 2007).

Specifically, supply gaps, even short-term, have the potential to create significant price volatility and commodity price uncertainty (Alonso *et al.*, 2007; Craighead *et al.*, 2007). Beyond that, even temporary shortages can cause a variety of other challenges for firms, including production bottle-necks, long lead times, and failure to deliver on-time products (Gaustad *et al.*, 2018). The further downstream firms are from material suppliers, the more severe these impacts can be: a phenomenon often referred to as the bullwhip effect (Lee, Padmanabhan and Whang, 1997). For instance, relating to the supply of a critical fibre like cotton, its global reach is wide, but current cotton production methods are environmentally unsustainable and not resilient against the rapidly changing climate—ultimately undermining the industry's ability to maintain future production (Wijnen, Groenestege and Business Models Inc BV, no date). Moreover, on the opposite end of the value chain, the waste management costs for textiles are around 200€/ton in various European member states and are expected to increase tremendously (Axelsson *et al.*, 2017).

Generally, each business decision will become more and more complex and impacting, evolving in the risk to quickly lose customers, suppliers or even employees. Organisational reputation and brand equity aggravation risks have already proved to lead to large economic losses (Patel *et al.*, 2018), as shown in figure 10. All these hazard prospects lead the way to uncertainty for future prosperity: "If no action is taken, fashion brands will likely find themselves squeezed between falling average per-item prices, deeper discount levels, rising costs for labour outpacing the growth in retail value, and resource scarcity along the value chain. All of these factors increase the pressure on fashion brands" (Kerr and Landry, 2017).

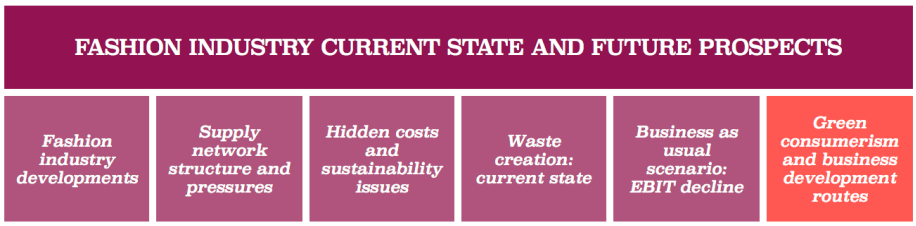
	Issues	Incidents
Social	Worker health and safety. Human trafficking. Below minimum wage. Child labor.	Rana Plaza collapse — Bangladesh.[4,5] Migrant worker exploitation — Turkey.[6]
Environmental	Discharge of untreated toxic chemicals into the ground and water bodies. High level of water consumption to produce cotton fabric. Production of wood-based fibers leading to deforestation.	Independent analysis of water around viscose-producing factories in India, China and Indonesia, where severe water pollution was detected.[7] Desertification of the Aral Sea.[8]
Quality	Spurious or inferior raw materials. Presence of harmful chemicals.	A large U.S. retailer where the use of Egyptian vs. Indian cotton was in question.[9] Significant levels of cadmium found in jewelry at major U.S. fashion retailers.[10] A large UK fast fashion retailer had to recall thousands of flip-flops after discovering a carcinogenic chemical used in the dye.[11]

Figure. 10 - Reported incidents impacting the fashion retail supply chain (Patel et al., 2018)

Nevertheless, the Global Fashion Agenda and the Boston Consulting Group also state that by realizing the potential savings and efficiency increases described in the Roadmap to Scale, companies will see an uplift in their profitability by 1 to 2 percent by 2030 (compared to the 2015 baseline), leading to a delta of possible improvement margin of 4-6% EBIT. In particular, enhancing resource efficiency in water, energy, and chemicals has the potential to improve a fashion company's EBIT margin up to 2-3 percentage points by 2030, as compared to the 2015 baseline. Regarding input resources, even though preferred materials are more expensive than conventional ones, it is estimated that switching over will increase EBIT by as much as 0-1 percentage points by 2030. The upfront investment will require approximately five to ten years to get to positive ROI, thus materials cost will increase in the short term but on the long run the price gap will shrink drastically and overall materials costs will fall. The reason behind the rising relative price competitiveness of preferred fibres lies in the assumption that raw materials prices of conventional materials will increase in line with their underlying input factors (especially energy, water, and labour) (Lehmann *et al.*, 2018).

Generally the estimates show that, even without considering the positive impact on brand building and risk management, the investments for the improvement of environmental and social performances do not lower the overall profitability (Lehmann et al., 2018). Thus, production methods that are more sustainable may cost slightly more, but they can also spur innovation and protect businesses from supply-chain shocks and reputation risks, resulting in greater resilience and profitability (Bouton *et al.*, 2016). Furthermore, long term strategies in this direction may attract greater and more innovative talents into the company, lead to higher levels of trust for a better collaboration along the supply chain, enhance interest from third-party organizations, facilitate financing from investors and relationships with banks and finally also induce earned media marketing through widespread word-of-mouth.

Thus, against all the unfavourable issues present in the industry there are indeed few signs of positive development opening up glimmers of hope. Specifically, the abovementioned Pulse of the fashion industry report also estimated that the overall benefit to the world economy could be about EUR 160 billion (USD 192 billion) in 2030 if the fashion industry were to address the environmental and societal fallout of the current status quo (Lehmann et al., 2018).



Given the above-displayed negative future scenario for unsustainable firms, it shall become diffusely reasonable to exploit the growing wave of consciousness among consumers and external stakeholders, through innovative design thinking and business models, as presented in the next chapter.

1.1.6. Green consumerism and business development

As shown in the previous sections, there is an apparent trend of rapid growth in the demand for apparel goods, particularly driven by emerging markets, such as Asia and Africa. Should growth continue as expected, total clothing sales would reach 160 million tonnes in 2050 – more than three times today's amount (Foundation, 2017). Beyond this, in order to explore the potential of sustainable and circular innovations relating to their barriers and drivers, it is first necessary to analyse the traits of development of this rising trend.

According to the GlobalData Survey for the Thred Up Resale Report, the percentage of consumers who prefer to buy from environmentally friendly brands grew from 57% in 2013 to 72% in 2018 (Thred Up, 2019). Likewise, the Nielsen Global Responsibility Report revealed that in 2015 66% of customers were willing to pay more for sustainable brands, where this percentage even reaches the value of 73% for millennials. (Nielsen, 2016) Hence, on the whole, consumer shifts point towards a more transparent, caring, and sustainable industry. (Pautasso, Ferro and Osella, 2019)

As unfolded by a McKinsey report, this tremendous business growth opportunity for fashion companies, may also be a pitfall for companies that choose not to grapple with the social and environmental risks of low-cost, resource-hungry production processes. Those risks could become even more pressing over time: as the millennial generation gains purchasing power, their high expectations that businesses will operate in a sustainable manner could have a big influence on shopping trends (Bouton et al., 2016). It is therefore fundamental to consider how future consumer targets will be much more differentiated and will all require higher service levels, greater traceability and stricter codes of ethics. For instance, to better address consumer themes, fashion players should focus on clearly understanding how to best use new social media channels and functions, how to optimise their store networks and experience and how to best deliver industry change toward greater sustainability. Both R&D and innovation will play vital roles in delivering short-

term sustainability targets and in reinventing fashion's economic model for longer term transformation (Beltrami, Kim and Rolkens, 2019). Entering the analysis of the design and development function, its key role in the transition to a more sustainable footprint is evident, as decisions here affect the entire value chain. In particular, the selection of materials affects in turn not only the footprint within dyeing and processing but also the end-of-use potential alternatives (Lehmann et al., 2018). Moreover, fashion holdings can actually drive change through their visibility, global supply chains and power in the market. They have the ability to influence purchasing behaviour by changing their value proposition and using their strong marketing know-how. They also determine the pace of introduction of new products and the material composition of clothing (Foundation, 2017). Secondarily, earlier stages as clothing manufacturing and fibre production should also follow the trend or even develop innovations upfront, since so many of the system impacts occur during their activities. On the other side, businesses involved in collection, sorting, processing, refurbishing, and recycling can play a key role in developing new closed-loop techniques and technologies as well as in providing valuable feedback that can inform designers and manufacturers about what is needed to maximise value after use. (Foundation, 2017)

Currently, what is possible to notice is a proliferation of bottom-up initiatives such as the maker and do-it-yourself movements, the consolidation of some exchange and sharing platforms, and the growing notion that younger generations tend to prioritize experiences over ownership. Particularly, impacts of this trend in the fashion industry have already been noticed in concrete matters as fast fashion companies have experienced a decrease in sales (Todeschini *et al.*, 2017). This pushes incumbents and innovative start-ups to propose a multitude of sustainable business models (as shown in figure x), even if they still lack of enough traction, financial viability and scalability.

In these regards, the Pulse of the fashion industry report provides a valid support of analysis through the tool of the *Pulse Curve*, which is used to model and trace the development of the industry towards environmental and social improvements.

Specifically, as shown in figure 11, the curve rises along with increasing Pulse Score levels, once companies set strategies and targets and lay the foundation to increase their environmental and social performance. The next bigger uplift is observed as they implement collaborative initiatives as well as improvement measures in their value chains. As they work with suppliers to introduce efficient production techniques, improve working conditions, and adjust their sustainable materials mix, the curve continues to rise. However, at a certain point companies continuing to implement these existing solutions experience only incremental change (Lehmann et al., 2018).

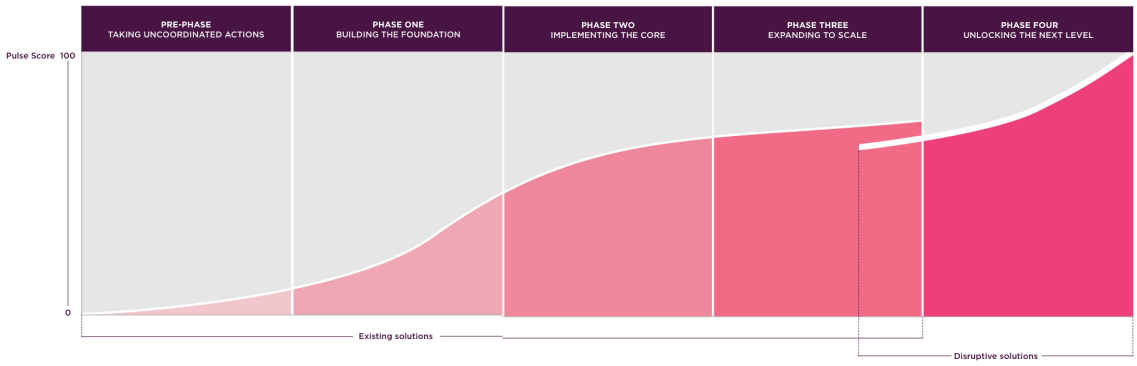


Figure. 11 - Pulse Curve (Lehmann et al., 2018)

Further investment starts to pay off less, demanding more effort. The curve's incline slows down and at that point the fashion industry will need to invest in transformational innovations and disruptive business models, to unlock the next level. In this sense, the Global Fashion Agenda and the Boston Consulting Group also suggest a CEO Agenda (Lehmann *et al.*, 2018), structured as follows:

- *Three core priorities for immediate implementation*:
  - Supply Chain traceability
  - Efficient use of water, energy and chemicals
  - Respectful and secure work environments
- *Four transformational priorities for fundamental change:*
  - Sustainable material mix
  - Closed-loop fashion system
  - Promotion of better wage systems
  - Fourth industrial revolution: embrace the opportunities in the digitalization

The first three priorities represent objectives for the progress of incremental innovations, while the last four, if effectively implemented and integrated, will play the key role for the fundamental change of the industry. The disruptions required may derive from each angle of the value chain. (Lehmann et al., 2018).

For this sake, there are some cases of apparel companies that have formed coalitions to tackle environmental and social challenges together, which helps to accelerate change and to mitigate the risks of working on these challenges alone (Bouton et al., 2016). Still, even if third party organisations are pushing for the revolution of the overall system, generally there is still a wide absence of innate cooperation, added to a lack of authority to enforce powerful business

coalitions. Through the words of Morten Lehmann, Chief Sustainability Officer at Global Fashion Agenda: "While it's encouraging to see 12.5% of the global fashion market taking concrete action toward circular business models, we must urgently address major roadblocks collaboratively to pave the way for a systemic shift towards circularity". Thus, as pointed out in the Pulse report, fashion companies must join forces with suppliers, investors, regulators, NGOs, academia, and consumers, especially for the improvement of the most difficult steps in the value chain: raw materials and end-of-use. The criticality originates from the nature of the industry. Being highly asset-intensive, innovations will need significant investments and pre-competitive collaboration to become commercially viable. Accordingly, the end-of-use stage is the section of the value chain where industry collaboration as well as regulatory support is most needed. The required upfront investment to put in place the necessary infrastructure to effectively sort and recycle and the technologies, as RFID, to provide information about materials and effective ways to recycle is simply too large to be managed by a single brand or retailer (Lehmann et al., 2018). Furthermore, the missing end markets and the high inefficiencies of the current systems hinder each pilot of singular initiatives to reach profitability or in most cases even breakeven.

Expanding the lenses, the present structure of the fashion supply chain is by itself a mean of prevention of harmonious development, since both market and negotiating power lie mainly in the hands of fibre manufacturers and retail fashion brands. Hence, the fabric of the supply network is grounded on asymmetric business relationships, locking up intermediate processors and small players in general. Through each step in the value chain, in fact, despite the strong advances of the mid-price companies, size continues to be a major determinant of performance in sustainability for the industry as a whole. (Lehmann et al., 2018)

On the other hand, neutral support would help building trust and transparency between buyers and suppliers without compromising business interests, regardless of relative size, and would enable the spreading of best practices of material circulation (Reverse Resources, 2017). However, independent third party organizations are still finding limited traction regarding the concretization of performance improvements. Namely, sustainability-related targets are quite fluidly set but fruitful actions are carried out only by a minority of firms, against the majority of them aiming at '*green-washing*' purposes, in order to get carried by the wave of market trends. (The Fashion Law, 2020)

Summing up, the gravity of the problem reflects a huge necessity to integrate the nascent proliferation of bottom-up innovations with the support of more standardised top-down initiatives, with the objective to regulate existing and novel market sections while creating win-win conditions for the whole ecosystem. Consistently, the amount of effort to reach fundamental change

within the industry is still vast and the interplay of many different actors and instruments will be expected. Sandin et al. (2015) estimate that, for several environmental impact categories, the impact per garment use in a western country must be reduced by 30-100% by 2050 if the industry is to be considered sustainable with regard to the planetary boundaries (Sandin, Peters and Svanström, 2015; Steffen *et al.*, 2015)

In these regards, the regulatory interest is wide and the efforts of the European Union are indeed already starting to build up the road for a sustainable, robust and profitable future, promoting different ways forward (European Parliament, 2019), as follows:

- *EXTENDING LONGEVITY OF CLOTHES*
    - Slow fashion
    - Fashion as a service
    - Improved collection for re-use, repair and up-cycling
    - Smart and instant fashion (instantly adjusting to the wishes of the consumer)

- *IMPROVED COLLECTION AND RECYCLING*
    - Circular fashion
    - Extended producer responsibility and in-store collection

- *TARGETING CONSUMERS*
    - Raising consumer awareness
    - Increased transparency and environmental labelling
    - Better washing and drying instructions

Upon these progress directions, the regulations respond with the EU Circular Economy Package and updated directives for waste, chemicals and textile products. Generally, great relevance is given to the same promising areas defined also in the Pulse of the fashion industry report: Sustainable Materials Mix, Closing the Loop, and Industry 4.0 (Lehmann *et al.*, 2018), demonstrating the value and potential of the circular economy paradigm in solving the issues of the current state.

1.2. CIRCULAR ECONOMY

The analysis of a conception that could potentially revolutionise the way society and business activities have been organised since the birth and growth of automatic manufacturing methods, shall begin from the study of the sources of related theories and the issues of the specific time period.

The concept of the circular economy originates, indeed, in the inability of linear production models to reconcile current levels of production and consumption with the limited availability of resources (Bradley *et al.*, 2018). This concept had already been highlighted in the mid-1960s by Boulding, who referred to the idea of a "Spaceship Earth without unlimited reservoirs of anything, either for extraction or for pollution, and in which man must find his place in a cyclical ecological system" (Kenneth E. Boulding, 1967). As discussed in previous sections, the pursuit of the take-make-dispose model, especially in the last 50 to 80 years, caused dreadful impacts over the whole ecosystem, seriously putting at risk long term human, animal and natural subsistence and ability to exploit resources for general value accretion. The demand for materials has quadrupled in the past 50 years (Allwood *et al.*, 2013). Additionally, emissions are forecasted to reach 60 billion tonnes by 2050, even with all current mitigation ambitions implemented. This sits in stark contrast to what is needed: achieving zero emissions by 2050 to keep a 1.5°C world. Hence, better use of existing stock is key to achieving the goals of both the Paris Climate Agreement and the Sustainable Development Goals (SDGs) (PACE Platform for Accelerating the Circular Economy, 2019).

Resource scarcity and the impacts of virgin materials represent indeed the main drivers for improving *resource efficiency*, namely the usage of Earth's limited resources in a sustainable manner while minimising impacts on the environment (EC, 2020). (PACE Platform for Accelerating the Circular Economy, 2019)

CIRCULAR ECONOMY							
Circularity paradigm definition	*Waste hierarchy*	*Circular Drivers*	*Circular Barriers*	*Circular business models for the fashion industry*	*Circular supply chain management*	*Digitalization and Industry 4.0 for circularity*	*Technologies for textile reuse and recycling*

In order to concretely delineate the potential of circular solution for fashion current state issues, it will be first critical to provide a complete and thorough definition of everything the paradigm embodies and may be applied to.

1.2.1. *Circularity paradigm definition*

In relation to the risks of disruptions in the supply of critical resources, a key component is to extend the useful life of raw materials that have already been extracted from the ecosphere (Gaustad *et al.*, 2018).

Accordingly, a circular economy is "*one that is restorative and regenerative by design and provides benefits for business, society, and the environment. It entails gradually decoupling economic activity from the consumption of finite resources, and designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital.*" (Ellen MacArthur Foundation, 2020)

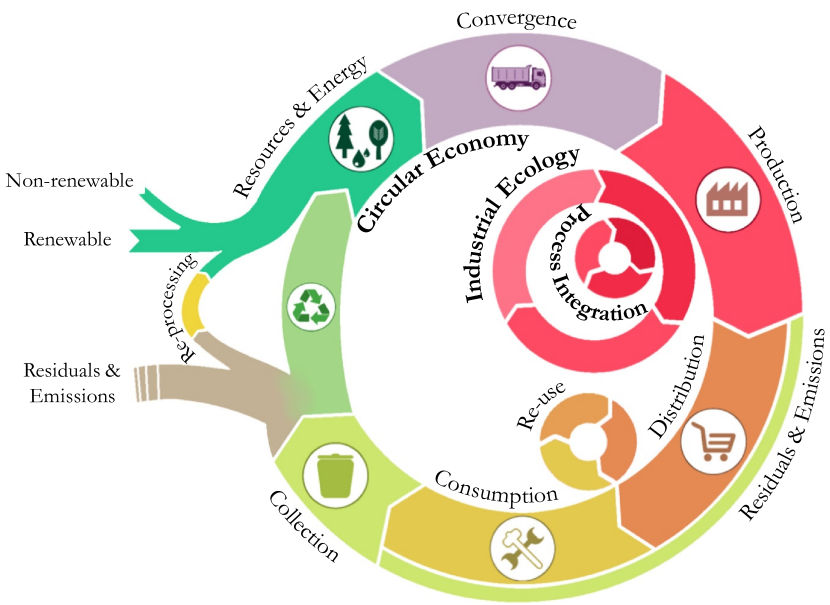


Figure. 12 - Integrative circular flows scheme (Walmsley et al., 2019)

Furthermore, circularity is regarded as part of a sustainable development framework, based on the principle of "closing the life cycle" of products, allowing for reduction in the consumption of raw materials, energy and water. It will promote new relationships among companies, which become both consumers and suppliers of materials, which are reincorporated into their production cycles (Buren *et al.*, 2016), as shown in figure 12. The circular agenda and low-carbon agenda are thus complementary and mutually supportive. Accordingly, circular business models and improved resource efficiency are also economically attractive means to enhance energy efficiency and renewable sources, methane abatement and to avoid deforestation (PACE Platform for Accelerating the Circular Economy, 2019).

Some 62% of global greenhouse gases are emitted during the Take, Process and Produce stages; whereas circular economy strategies which extend lifetimes and use-intensity may cut these emissions (PACE Platform for Accelerating the Circular Economy, 2019). In particular, it is estimated that CE practices could reduce CO2 emissions by 48 % and create a net economic benefit of EUR 1.8 trillion until 2030 in the Europe Union (EU) (Kirchherr *et al.*, 2018). For instance, figure 13, shows the projected climate change, freshwater consumption and human health impact reduction, if apparel achieves a 40% recycled fibre target by 2030 (Lehmann *et al.*, 2018).

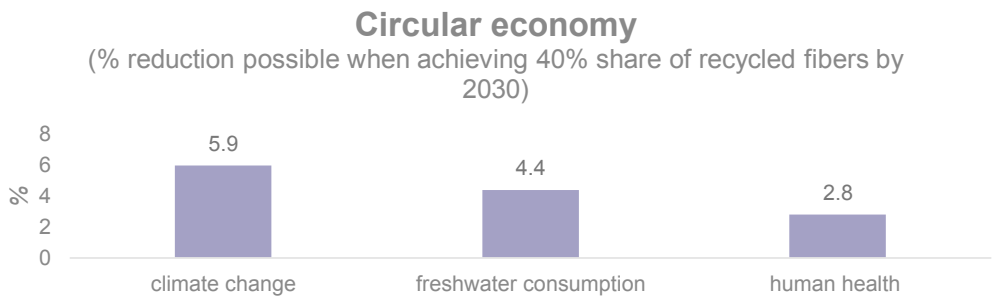


Figure. 13 - Projected climate change, freshwater consumption and human health impact reduction, if apparel achieves a 40% recycled fibre target by 2030 (Lehmann et al., 2018)

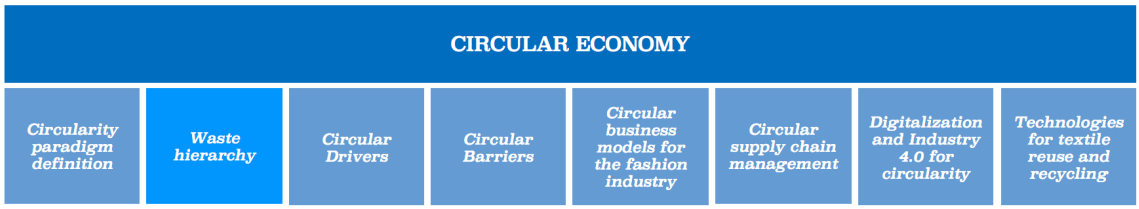
Apparently, the knowledge of the theoretical characteristics and implications of the circular framework seem quite widespread in the businesses' fabric. The problem lies in the actual volumes of flows effectively maintained in a loop, gaining additional and diverse lifecycles. According to Circle Economy, our world is only 9% circular and the trend is negative, due to continuous upward-sloping trend in resource extraction and greenhouse gas emissions (PACE Platform for Accelerating the Circular Economy, 2019).

Specifically, the fashion industry is largely a system in which valuable resources are extracted and turned into products that are used for a short time, before being thrown away. In these regards, the Ellen MacArthur Foundation

applies key circularity principles and presents the perspective of '*A new textiles economy*', in which clothes, fabric, and fibres are kept at their highest value during use, and re-enter the economy after use, never ending up as waste. This would provide a growing world population with access to high-quality, affordable, and individualised clothing, while regenerating natural capital, designing out pollution, and using renewable resources and energy. Such a system would be distributive by design, meaning value is circulated among enterprises of all sizes in the industry so that all parts of the value chain can pay workers well and provide them with good working conditions." (Foundation, 2017)

Hence, circular economy has undoubtedly become a central trend in the fashion industry (Reverse Resources, 2017). For instance, it is defined as one of 3 Key Trends 2018 in VF Made for Change Report. The giant holding points out the necessity to find ways to meet the growing demand for clothing and related products, while maximizing the value derived from clothing produced. Specifically, they believe in the possibility to unlock value and new revenue streams by selling previously owned, damaged-and-repaired or used products. (VF, 2018)

This also mirrors the need to differently prioritize the various EOL alternatives, favouring the less environmentally and economically impacting.



Once the general definition of circular economy is given, the following chapter shall focus on its natural translation into the European regulative system, which aims adding a degree of prioritisation among the diverse circular models, in order to achieve true and consistent sustainability improvements.

1.2.2. *Waste hierarchy*

The European directive 2008/98/EC standardises the concepts of waste, recycling, recovery and introduces the concepts of the 'polluter-pays-principle' and 'extended-producer-responsibility' schemes, while also putting forward a priority order to be applied to all policies and Member States economic activities, i.e. the 'waste management hierarchy' shown in figure 14 (EC, 2019).

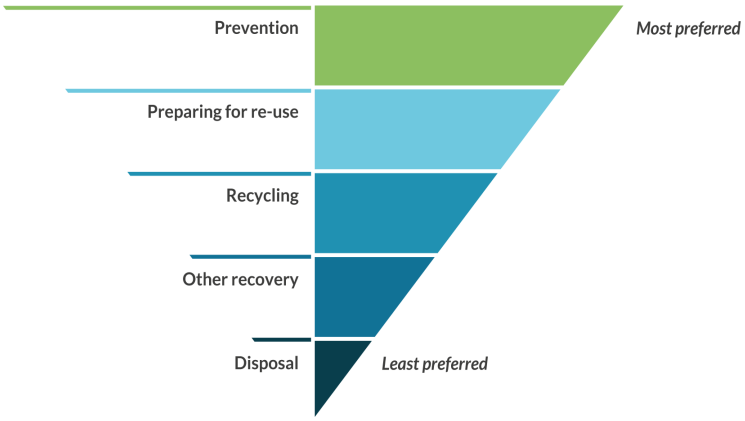


Figure. 14 - Waste Hierarchy (EC, 2019)

First of all, it is here necessary to properly define the concept of 'waste' as "*any substance or object which the holder discards or intends or is required to discard*". In this regards, '**prevention**' means "*measures taken before a substance, material or product has become waste, that reduce:*

- ✓ *the quantity of waste, including through the re-use of products or the extension of the life span of products;*
- ✓ *the adverse impacts of the generated waste on the environment and human health; or*
- ✓ *the content of harmful substances in materials and products;*"

'**Re-use**' implies "*any operation by which products or components that are not waste are used again for the same purpose for which they were conceived*; while 'preparing for re-use' means *checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing.*"

'**Recycling**' implies "*any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations.*"

'**Recovery**' implies "*any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy.* "

'Disposal' implies "*any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy.*"

(European Parliament and Council, 2008)

Hence, in line with the circularity principle of maintaining value as high as possible causing the lowest possible impact, also this hierarchy prioritizes the development and innovation of systems for waste prevention and resources re-utilization. Inherently, the directive supports the transition from an economy based on the sale of goods to one based on the sale of performance (Genovese *et al.*, 2017), embodying the theories of '*servitization*'. Dematerialization, intended as reduction of materials needed to provide a desired economic service, is indeed another important strategy that supports the resource efficiency goals of the circular economy (Gaustad *et al.*, 2018). In other words, according to the Circle Economy, actions to drive the transition from a throughput economy of 'Products that flow' (reaching their end-of-use typically within a year) to one based on 'Products that last' will transform the social contract; i.e. it will slow environmental degradation and reduce social inequality. Furthermore, it is no longer enough to think of *financial value* as something created simply by turning extracted materials into products. The circular model sees the financial service value of existing assets being optimised and retained for as long as possible (PACE Platform for Accelerating the Circular Economy, 2019). Namely, transitioning to a circular economy in turn implies a transition from value-added to value-maintained (Webster *et al.*, 2014).

Consumers become indeed increasingly demanding about the features of the experience of the products, about the support during sale and after-sale, but not about ownership anymore as they worship usage and service quality more. It is practically necessary to change the way to compete, by modifying how value is created, captured and delivered; which coherently backs up a statement by Porter (1991) that affirms: "the conflict between environmental sustainability and economic competitiveness is a false dichotomy based on a narrow view of the sources of prosperity and a static view of competition (Porter, 1991)

Current statistics represent the starting fuse for such a global economic and environmental rethinking (PACE Platform for Accelerating the Circular Economy, 2019):

- *The majority (60%) of materials enter the economy in the form of Products that Flow and a smaller fraction as Products that Last.*

- *The delivery of services is responsible for more than 60% of all value-add compared to less than 40% for products manufacturing.*

- *As all value-add in the production and use of a product depreciates with consumption over time, this shows the importance of slowing the flow by extending the functional lifetime.*

In support, estimates show that if the number of times a garment is worn is doubled on average, the GHG emissions would be 44 % lower (Foundation, 2017). Generally, recent studies demonstrate that textile reuse and recycling are more beneficial for the environment than landfill and incineration (Bukhari, Carrasco-Gallego and Ponce-Cueto, 2018). Indeed, when reuse is not possible recycling still provides positive impacts and economic benefits. According to Dutch aWEARness's calculations, textiles recycling cuts raw materials demand on average by 61% and can promote energy, carbon dioxide and water savings of 64%, 73% and 95%, respectively (Stahel, 2013). Estimates will then fluctuate quite a lot among the different fibre alternatives.

Figure 15 shows a classification of all possible routes for materials flows, where the shorter loops will notably be the most preferred in accordance with the analysis carried out above.

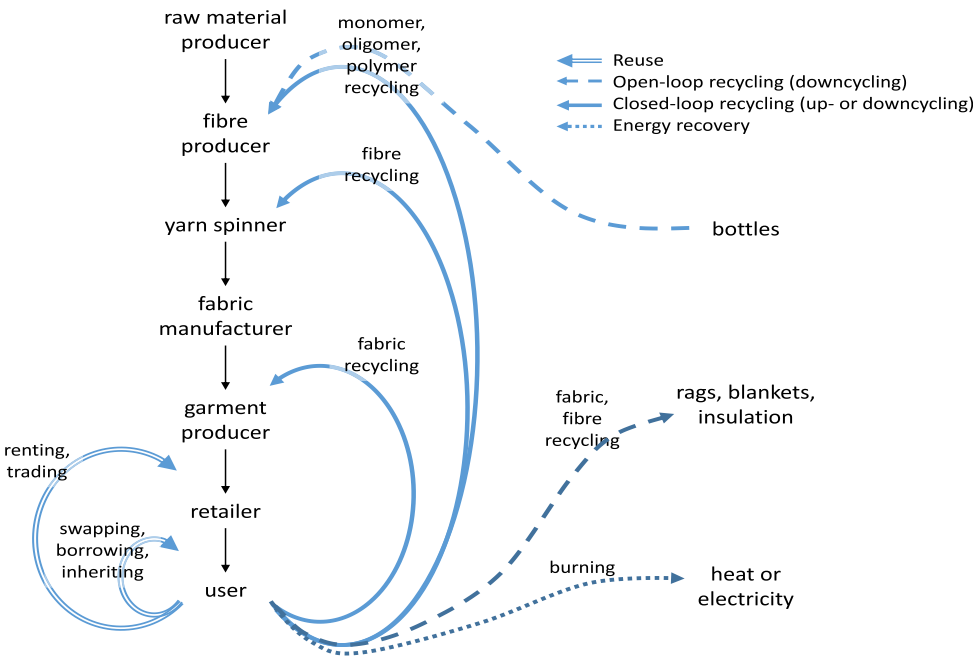


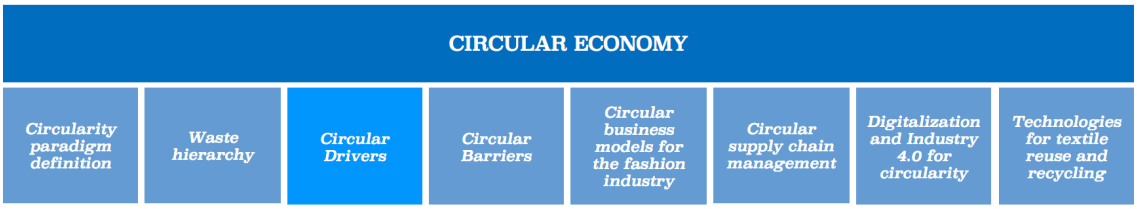
Figure. 15 - A classification of textile reuse and recycling routes (Sandin and Peters, 2018)

At this point, it is necessary to deepen the detail level and differentiate between '*Open-loop*' and '*Closed-loop*' recycling. The former presumes that materials will be cascaded into different industrial sectors to lower value uses due to degradation in quality; whereas the latter presumes to keep materials flowing within the same product value chain (GreenBlue, 2017). Accordingly, open-loop systems generally have the chance to move resources where they are mostly demanded in a specific time frame gaining economic value, whilst the extent of value recovery in a closed loop supply chain is often limited because it does do not include secondary supply chains and/or involve new auxiliary channel members (Moula, Sorvari and Oinas, 2017). However, the case of the fashion industry is emblematically different. Down-cycling causes indeed a great loss of economic value, on one side because end products, as matrasses, insulation and wiping cloths, have much inferior prices; on the other because resources reach their final life stage and cannot be recycled anymore into other useful options. Hence, in regards to the resolution of fashion current system issues, the greatest potential is for closed loop recycling, where material is designed and captured for fibre to fibre recycling (Girn *et al.*, 2019). This may also be consistently linked to the concept of industrial ecology that promotes the transition from open loop to closed loop material cycles, the use of renewable energy and that leads to less wasteful, and thereby more resource efficient processes (Jensen and Remmen, 2017).

Further on, Urbinati et al. (2017) also pointed out that business models have not considered the degree of adoption of circularity; i.e. they are studied under a Boolean 'on' or 'off' approach. Hence, their work identified three degrees of adoption of circularity; downstream circular adoption, upstream circular adoption, and full circular adoption. Downstream circular adoption involves a marketing campaign for the reused or remanufactured products, whereas the upstream circular adoption concerns only with the activities that establish an effective relationship with the supplier. However, the full adoption involves the adoption of circularity at both the external and internal levels of the firm (Urbinati, Chiaroni and Chiesa, 2017b)

Hence, it is clear how the normal development of the ecosystem shall start from separated projects on single upstream or downstream processes and then reach the desired goals once a majority of firms deploy a full adoption. Similar to the fossil-fuel subsidy reform, a step-by-step action plan should be developed for the fashion industry to move from linear to circular. Monetary, regulatory and supportive measures need to be considered in balance and impact analysis carried out (Reverse Resources, 2017).

Each of these measures shall rely on the drivers of success while attempting to solve or limit the barriers against the transition towards the circular fashion industry paradigm.



The previous chapter disclosed the potential benefits obtainable through different circularity approaches. In respect to this, the review shall now systematise the variety of drivers supporting the relative full adoption.

1.2.3. *Circular drivers*

As synthesized in the literature review work of Gusmerotti et al., the main drivers for circular actions in manufacturing firms may be subdivided according to the management theory considered (Gusmerotti *et al.*, 2019):

- *Institutional Theory and pro-environmental practice*
    - Legal compliance
    - Anticipate future legal requirements
    - Reduce the company's environmental impacts
    - Reduce products' environmental footprint
    - Improve the company's image
    - Improve clients' satisfaction

- *Natural Resource-Based view and pro-environmental practice*
    - Improve efficiency (reduce costs)
    - Gain a competitive advantage over competitors
    - Reduce the company's dependence on raw materials
    - Reduce risks related to supply of raw materials

The majority of these, derive from the current state challenges examined in the previous sections, with a fil rouge related to general value enhancement and maintenance. Accordingly, organizations that are driven either by economic benefits, regulatory pressures, environmentally conscious leaders or that are dependent upon scarce natural resources are more likely to adopt circular economy practices. In particular, economic efficiency is predominant in a widespread number of cases, since it is also linked to shareholder expectations (Hart, Milstein and Caggiano, 2003). Focusing on traditional manufacturing companies that are proactive in terms of the circular economy, three main clusters emerge: one basing on resource “optimisation” principles,

one aimed at satisfying market expectations and finally one made of "circular champions". These latter have understood that implementing the CE paradigm involves re-thinking the entire value chain, starting from product design and the purchase of raw materials, down to improving the efficiency of production processes and making the customers more aware of the impact of the consumption phase. (Gusmerotti *et al.*, 2019).

Furthermore, in respect to the fashion industry, keener attention shall be dedicated to supply chain integration and resources traceability. These would allow to fully profit from the closed loop benefits. In particular, a study by Reverse Resources on garment factories in Bangladesh but with similarities worldwide, displays how creating a digital layer for the industry to manage ownership issues collectively throughout supply chains (e.g. with block-chain tokens) with proper data coverage would give an opportunity to create a full perspective of the material flows and efficiency of resources (as shown in figure x). This would give proper tools for the industry to analyse how to shorten the loops, move towards resource effectiveness and thereby reach profound circular economy. A measurement and data gathering system should be set up per each purchase order as well as in total per factory, supplier and buyer (Reverse Resources, 2017).

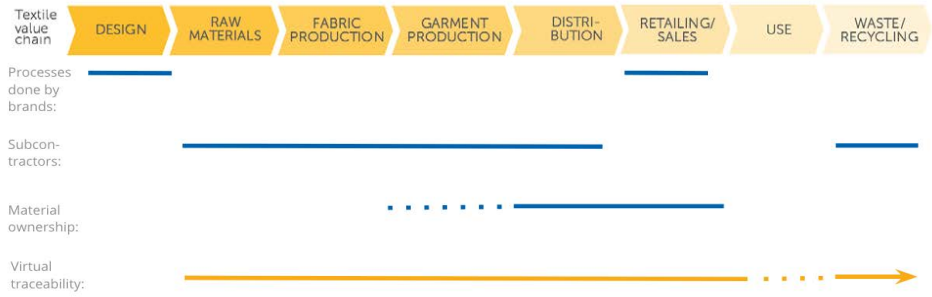
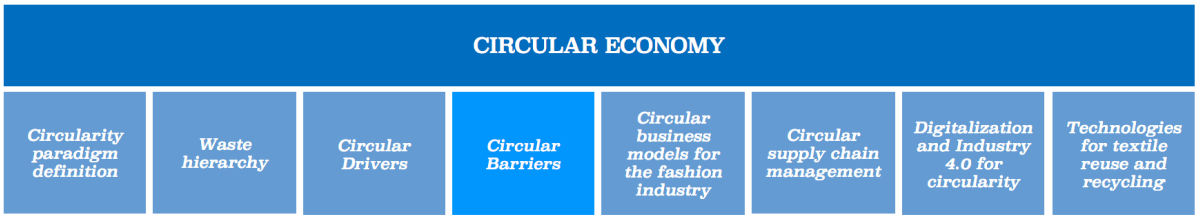


Figure. 16 - Distribution of responsibilities and ownership through global supply chains (Reverse Resources, 2017)

Still, in the current situation the majority of flows lacks of visibility and brands control. The case of production leftovers is emblematic as these excesses usually are gathered all together, without separating colours or fibres, and are then sold to third parties for down-cycling making small profits that for those garment manufacturers actually count fairly a lot (Reverse Resources, 2017). Thus, the pathway from the current state to the potential closed loop should follow the common language of economic convenience in order to become effectively rooted in the tactical decisions of all supply chain actors. For instance, getting the pricing right and setting up a supportive system for material circularity in shorter loops can incentivise the fashion industry to start following the waste hierarchy naturally (Reverse Resources, 2017).

Finally, economic convenience and viability shall be integrated with the polluter-pays-principle to actually facilitate the application of circular innovation also into standardised processes and systems.



If on one side the drivers push for systematic circular change, on the other side of the coin there will be a broad diversity of potential stumbling blocks that may hamper the success of any initiative.

1.2.4. *Circular barriers*

Most of the obstacles that hinder the full adoption of circular business model tools and innovative technologies, concern the practical implementation, expansion and settlement in the organizational fabric.

A study published by the World Economic Forum (2014) states that the complexity of managing material flows increases dramatically due to multi-layered bills of materials (Ellen MacArthur Foundation and Mckinsey & Company, 2014) Furthermore, closed-loop processes imply changes in product design, production, and logistics systems, which will require improved collaboration within supply chains (Ritzén and Sandström, 2017) Consistently, the difficulties of change management inside organisations appear indeed to be the highest barrier, since the status quo needs to completely twisted.

Secondly, another relevant barrier commonly found in any innovation projects is about the financing burdens. In particular, as FFG and BCG expose, asset intensity is an important factor in the pace and path of technology development and scale. The science and engineering involved in building and deploying hard-tech assets, as the ones demanded for the infrastructures in circular systems, require specialized skill sets, customized tools, and often orchestration of a wide set of stakeholders across the fashion supply chain, including facilities operating in less developed countries. Consequently, hard-tech ventures are in many cases less mature, have more substantial capital needs, and offer a different return-on-investment profile than typical soft-tech ventures. About

45% of the financing demand in the fashion industry is indeed driven by raw materials and end-of-use solutions, where technologies in both areas tend to have longer and more capital-intensive time-to-market cycles. For instance, chemical recycling innovators need to build several thousand recycling facilities to process the world's annual fibre waste. Orchestrating multiple players is essential not only to meet pure funding needs, but to secure the right support, accumulate order volumes, and install additional infrastructure such as collection schemes for recycling. In particular, the financing need curve will follow the one depicted in figure 17. In the technology gap, innovators need risk capital to create working technologies and build viable business models with minimum viable products (MVPs); whereas, in the commercialization gap, they need a different form of growth capital to advance proven models to commercially viable scale (Fashion for Good and Boston Consulting Group, 2020).

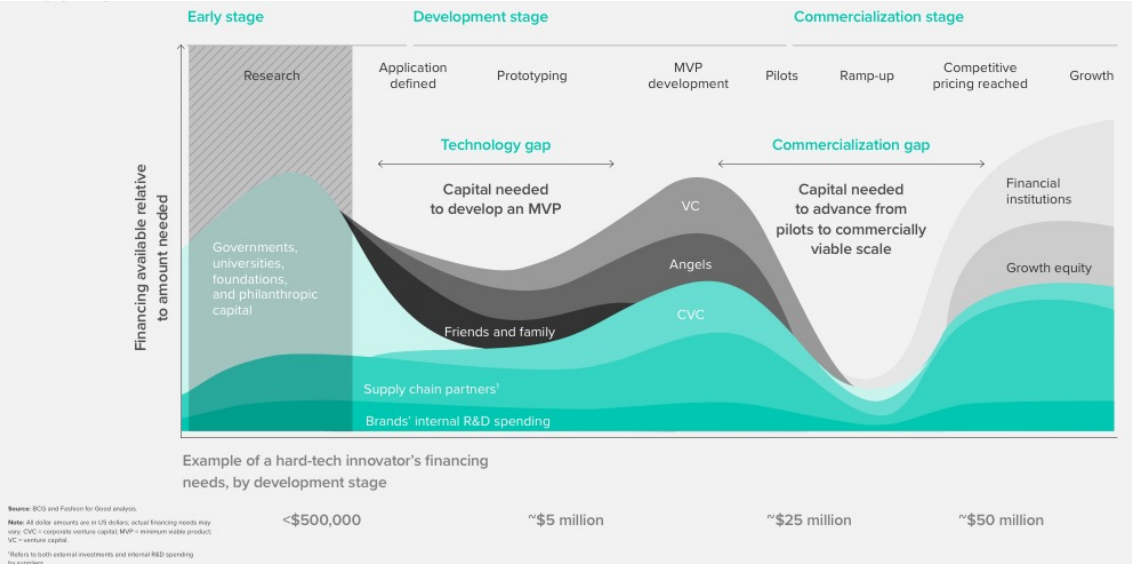


Figure. 17 - Typical Financing Demand and Supply Landscape for a Hard-Tech Innovator (Fashion for Good and Boston Consulting Group, 2020)

In addition, closing the loop via circular practice can only be applied if there exists a regular demand for remanufacturing and recycled materials (Reverse Resources, 2017), which is currently still limited and highly fluctuating. Hence, wider collaboration and policies accuracy is necessary to address also the topics of consumers' behaviour and education, end-of-life processes and recycling technologies.

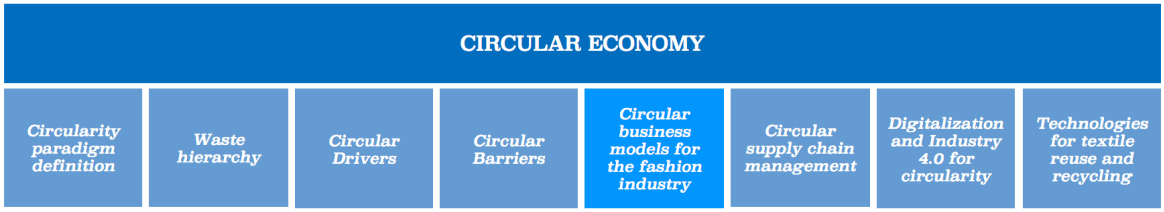
The following scheme further summarises the main barriers for the concrete implementation of circular economy, according to three actors' categories and focusing on factors specific only to the fashion industry (De Paoli, 2015; Prieto-Sandoval, Jaca and Ormazabal, 2018):

- Consumer behaviour and education
    - *Poor consumer demand for recycled textile products, which tend to be perceived as lower quality*
    - *Consumers' unawareness that textiles should be recycled and how they can be disposed of in the most responsible manner*
    - *Lack of traceability in the global waste chain*
    - *Policy frameworks in which collectors, recyclers and waste mangers operate*

- Disposal practices, collection and sorting infrastructure and process
    - *Collectors focus on "re-wearable" textiles, neglecting streams of waste that require costlier recovery solutions*
    - *Lack of mainstreamed, up-scaled process of know-how to collect and sort textiles by fibre type*
    - *Low availability of infrastructure on local and regional levels*
    - *Lack of traceability in the global waste chain*
    - *Policy frameworks in which collectors, recyclers and waste mangers operate*

- Recycling technologies
    - *Lack of commercially viable recycling technologies for low-grade textiles fraction*
    - *Lack of mainstreamed, up-scaled processes and know-how to separate fibre types from the mixed blends and composite structures*
    - *Costly recovery process*
    - *The recycling end-market dominated by low quality materials and blends*
    - *Costly logistics and low availability of textile recycling plants on local and regional levels*
    - *Lack of traceability in the global waste chain*
    - *Policy frameworks in which collectors, recyclers and waste mangers operate*

Specifically, it has to be pointed out that the increase in market value thanks to the digitally-enhanced role of remanufacturing is mainly obstructed by the current lack of incentives for factories to provide accurate data, relating to the current cost reporting procedure (Reverse Resources, 2017). This demonstrates the depth of the need to revolutionize also the current pricing logics and value propositions.



The previous chapter displayed all the factors to worry about when designing a circular business model, product or supply chain structure. The next chapter will thus focus on the existing factual paradigms developed for the exploitation of driving factors and the minimisation or complete overcoming of related barriers.

1.2.5. *Circular business models for the fashion industry*

In 'A new textiles economy', companies will need a variety of sales and business models to adapt to diversified opportunities of demand trends (Foundation, 2017). Circular business models may thus contribute to the slowing of resource loops by encouraging long product life and reuse of products, closing loops through capturing the residual value from by-products or "waste" through business model innovation, and narrowing resource loops through product design and manufacturing efficiencies (Bocken et al., 2016). However, as already anticipated, CBMs are not yet widespread in business practice because of the need to change the key building blocks of the business, as well as the need to go against dominant business paradigms (Ritala *et al.*, 2018). This requires change at the citizen, business and policy levels (Ghisellini, Cialani and Ulgiati, 2016).

In order drive the ease and success of the transition, MacArthur et al. (2015) proposed the CE principles oriented ReSOLVE framework that includes (Ellen Macarthur Foundation; McKinsey & Company, 2015):

1) ***Regenerate*** – based on the conversion of waste into a source of energy for different operations along the value chain.

2) ***Share*** – based on the sharing of resources to extend the life cycle viá recovery operations from the economic point of view.

3) ***Optimize*** – based on technology-centred strategy, which requires the organization to use digital manufacturing technology such as principles of I4.0 to reduce waste in the operations system across the supply chains.

4) ***Loop*** – based on the restoration of the value of products viá recovery operations.

5) ***Virtualize*** – based on the service-focus strategy that allows virtual and dematerialized products.

6) ***Exchange*** – based on introducing advanced and renewable goods instead of old and non-renewable goods.

These guidance principles aim to support the concrete and complete implementation of circular innovations reaching full adoption status. In order to fulfil a systemic change through textile and clothing companies, they shall be applied in connection to the objectives of the New Textiles Economy (Foundation, 2017):

- ***Phase out substances of concern and microfiber release*** – ensure that the material input is safe and healthy to allow cycling and to avoid negative impacts in the production, use and after-use phase

- ***Increase clothing utilization*** – designing and producing clothes of higher quality and providing access to them via new business models: >>> Scale-up of short term clothing rental, durability attractiveness, brand commitments and policy actions.

- ***Radically improve clothing recycling*** – working on improvements of recyclable-by-design conceptions, technologies for tracking, demand side actions and collection systems

- ***Make effective use of resources and move to renewable inputs*** – sourcing virgin materials from renewable systems, developing more effective and efficient production process and accounting for negative externalities

Consistently, the Global Fashion Agenda further set 213 more precise targets in July 2019 referring to 4 main action points (Global Fashion Agenda, 2019):

- *Implementing design strategies for cyclability (41% of total targets)*

- *Increasing the volume of used garments and/or footwear collected (24% of total targets)*

- *Increasing the volume of used garments and/or footwear resold (13% of total targets)*

- *Increasing the share of garments and/or footwear made from recycled post-consumer textile fibres (22% of total targets)*

The fashion industry could gain much higher economic value from a more holistic approach to the material circulation throughout global supply chains. According to Reverse Resources, shortening the loops of circular supply chains is a major unexplored business opportunity for growth within the industry sector. Shorter interconnections can unlock the potential for open data sharing and virtual traceability of fabrics and fibres through supply chains. Access to information is key to building effective circular economy in the global fashion industry, but demands cooperation and open discussion (Reverse Resources, 2017).

Modifying the main differentiating process of the fashion industry may virtually solve many among the challenges of the supply chain current state, since strategies carried out by brands influence both upstream and downstream decisions. Incumbents and start-ups are already exploring the options of '*eco-design*', where the first prerequisite would be the durability of the product, leading automatically to minimised impacts in terms of waste and production processing as well as the perception of higher quality. This aspect has indeed been the strategical layout of most luxury brands and high-performance fibre producers since their beginnings. In its broadest sense, durability implies a long life or may also refer to the length of service or tenure that is provided by a product. It is this latter definition that may offer an insight into what longevity for clothing is. This implies an influence over clothing's diverse functional aspects (WRAP, 2015b):

- *Physical durability*: design for physical durability considers construction and strategic reinforcing in order to create products that can resist damage and wear.

- *Emotional durability*: in order for a product to last, in addition to physical durability, design also needs to consider the product's ability to stay relevant and desirable to the consumer.

The novelty of the waste prevention rethinking lies in the efforts to facilitate the end-of-life management of the product, extending its life cycle even further. Thus new traits referred to eco-design include the ease of de-manufacturing and recyclability, considering and managing the effects of the design choices regarding material blends, trimmings, finishing and dyeing processes. Wahl and Baxter also add that designing for sustainability requires that the design also influences consumer habits, lifestyles and practices, such as garment consumption, laundry, reuse and recycling (Wahl and Baxter, 2008). Consistently, extending the lifespan of clothing can be achieved not only by increasing product durability through higher quality, but also by informing the consumers about the expected lifetime and by increasing product satisfaction (Niinimäki and Hassi, 2011).

Maintaining the boost for a shift from an economy based on the sale of goods to one based on the sale of performance (Stahel, 2013), the alternative

movement to eco-design regards the maximisation of what can be done with the present products and resources. Typical solutions lie in improving the utilisation rate, which can be achieved by prioritising access over ownership (PACE Platform for Accelerating the Circular Economy, 2019). According to Elizabeth Segran from Fast company, "Shopping ethically has often been perceived as a luxury, because of the price points...The good news is that we now live in the golden age of second-hand shopping", and this supports both the increase consciousness of consumers and also their desire to be constantly seen in new various styles (Thred Up, 2019). In particular, the role of online platforms and related retail activities turns critical. As driver of life cycle extension and environmental impacts limitation, collaborative consumption has been defined as "people coordinating the acquisition and distribution of a resource for a fee or other compensation" (Belk, 2014).

The business models supporting re-use maximisation comprise diverse brand-led leasing programs, individual customer-led collective sharing models or resale and re-commerce projects. The potential embodied in this revenue streams is quite high thanks to a fertile ground of worldwide markets, especially in developing countries, already used to re-use of apparel products. According to Secondary Materials and Recycling Textiles [SMART], over 70% of world population uses second hand clothes (SMART Secondary Materials and Recycling of Textiles, 2020). Future trends provide confidence as well: it is predicted that the second-hand market for clothes will double in the next ten years, and quality second-hand clothing will comprise a third of closet utilization by 2033. In respect to this, the main growth driving factors are (Fibre2Fashion, no date):

- *Budget Shopping*: It allows variety in the wardrobe at affordable prices which can be replaced at shorter durations without harming the environment. Moreover, this makes luxury affordable where 1st hand buy is out of budget.

- *Environmental protection*: Reuse reduces pressure on virgin resources, polluting emissions, water and energy consumption, demand for dyes and fixing agents.

- *Waste prevention*: This links with a reduction of landfill space requirements and environment-polluting consequences. Certain synthetic fibre products do not decompose, while natural fibres such as wool who decompose but produces methane which contributes to global warming.

- *Vintage factor:* Vintage clothes are usually collected as a part of special collections in a wardrobe.

According to the Ellen MacArthur Foundation, by selling used clothing alongside new clothing, fashion retailers offer an appealing and convenient

option (i.e. using the usual channels for shopping). This could help reposition clothing resale from a fringe to a mainstream activity. Introducing such resale activity has the potential to be a low-risk and high-reward activity for brands, as it would create additional profits while feeding into the perception of quality, and promoting a brand's interest in increased usage of its clothing. (Fibre2Fashion, no date). In support to this, the Thred Up 2018 Resale Report exposes that the perception of previously owned garments has changed; used garments are no longer seen as dirty / outdated but instead customers place value on second hand, vintage products (Thred Up, 2019). Furthermore, a leading Re-commerce model found that 80% of customers returning garments utilise their voucher to purchase a new item from the same brand. Thus re-commerce models can also grow a brand's wallet share with existing customers (Accenture Strategy & Fashion For Good, 2019). Still, the potential issues of problem shifting related to increased customer transportation might offset the benefits gained from reduced production. This highlights the need for accounting for the logistics when implementing collaborative consumption business models, for example by locating physical rental services or clothing libraries in locations close to customers and/or public transportation (Zamani, Sandin and Peters, 2017). Generally, short term profitability and long term economic sustainability will also be a matter of economies of scale, marketing efforts and value proposition accuracy effectively aligned with the evolving consumption preferences, in order to provide a desirable experience and customer service even more than the single products. There is indeed a risk of cannibalization effects that needs to be managed, so to avoid that sales via new models replace the sales in traditional retail channels. In addition, the sensibility of operating margin to discount voucher value is critical in the lower segments of the market, obstructing the viability of the models applied especially for discounts from original price of over 50% (Accenture Strategy & Fashion For Good, 2019).

Specifically, resale may take the form of online second-hand shops, online resale platforms, second-hand offline retail, sell-to-redistribution, collaborations with charities, partnerships with solution providers, rental services (Fibre2Fashion, no date).

Rental options may be of two types: one-off rental of a garment for a short time period; or on the other side, a subscription model with a monthly fee paid for the access to a range of garments (Accenture Strategy & Fashion For Good, 2019). Driven by fashion tech companies with expertise in reverse logistics and inventory management, Rental is transforming from an outdated model to an innovative, modern way of consuming fashion (The Guardian, 2020). The projected market size entails a worth of $1.9bn globally by 2023 – a doubling in value from 2017 (Accenture Strategy & Fashion For Good, 2019).

According to an Accenture and Fashion For Good report, Rental appears to be very attractive in higher-value segments, Subscription-Rental has consistently

strong potential, while generally Re-commerce appears to be the most financially attractive of the models analysed. As shown in figure 18, the margin potential varies significantly by segment. Luxury would appear to represent the biggest opportunity, while new variable costs associated with each model make the most convenient market segment, the 'Value Market', consistently challenging. For the Mid-Market and Premium segments, specific product characteristics that influence 'rentability', for example how often it is worn, could drive improved viability. Furthermore, retaining an engaged customer base and learning more about their product usage habits could be a key long-term, structural advantage for all circular models over traditional retail. In particular, rental allows retailers to engage customers at a lower price, for specific one off, or rare occasions, whilst maintaining quality and reputation. On the other side, subscription rental maximises the concept of 'Access over Ownership', offering variety and novelty at a fraction of the normal price. (Accenture Strategy & Fashion For Good, 2019).

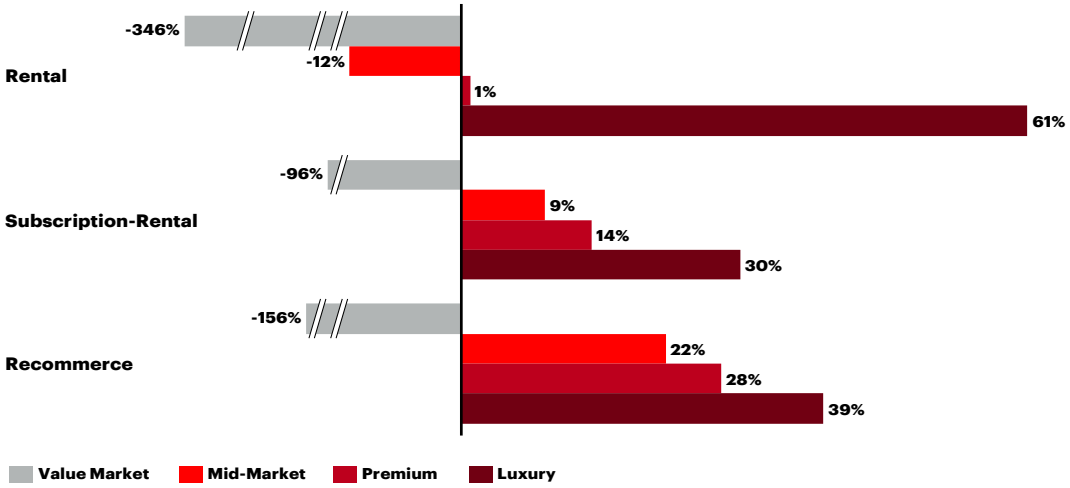


Figure. 18 - Operating margin by circular business model (Accenture Strategy & Fashion For Good, 2019)

The barriers that could hamper the complete efficacy of these BMs may be the increase in net-new costs such as logistics, packaging or manpower, the reduction in quality and life expectancy of garments and finally the consumer perception of affordable fashion as poor quality (Accenture Strategy & Fashion For Good, 2019).

Regarding subscription models, it is critical to monitor the 'churn rate' and manage it through price point, convenience, number of garments, and additional incentives. According to Frankenfield, it is defined as "the monthly percentage rate at which an existing customer stops subscribing to a service" (Frankenfield, 2019). Furthermore, the viability of the model also depends widely upon the total number of times a garment is exchanged during a subscription (as shown in figure x). This sensitivity is linked to new variable costs, including postage, packaging, laundry and manpower, which are

incurred for every exchange with no additional revenue uplift; on the contrary to what happens in single articles rentals (Accenture Strategy & Fashion For Good, 2019).

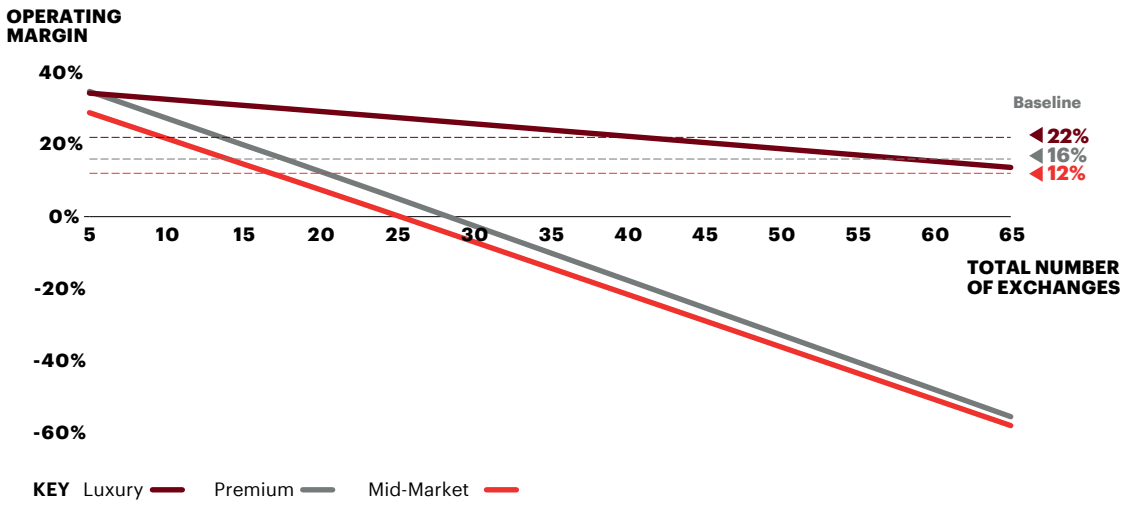


Figure. 19 - Operating margin as a function of total number of exchanges (Accenture Strategy & Fashion For Good, 2019)

Generally, it is noticeable how the luxury and premium segments will be the foundation on which to build the system up, in order to drive the diffusion and exploitation of these life extension models. The management of the change in consumption patterns and of the differentiated growth or contraction of each market section will thus need to be combined with a balanced set of incentives in order to induce a systemic transition in both consumers' and producers' mind-set.

Summing up, figure 20 shows in an aggregate way all the trends pushing towards a circular fashion system and the implementation routes to reduce, reuse and recycle excesses along the whole supply chain. Notably, according to Lacy and Rutqvist a more widespread and comprehensive change in the economy, i.e. the entire economy becoming circular, cannot rely only on radical innovations, which might be beyond the reach of most companies (especially SMEs) (Lacy and Rutqvist, 2015). Traditional business models shall progress through incremental innovations aimed at boosting circular principles in their value chains (Gusmerotti *et al.*, 2019). Hence, it is a question of right balance in disruptiveness levels within different companies and sectors, whereby resource optimisation and supply chain management will constantly play a critical success factor in each case.

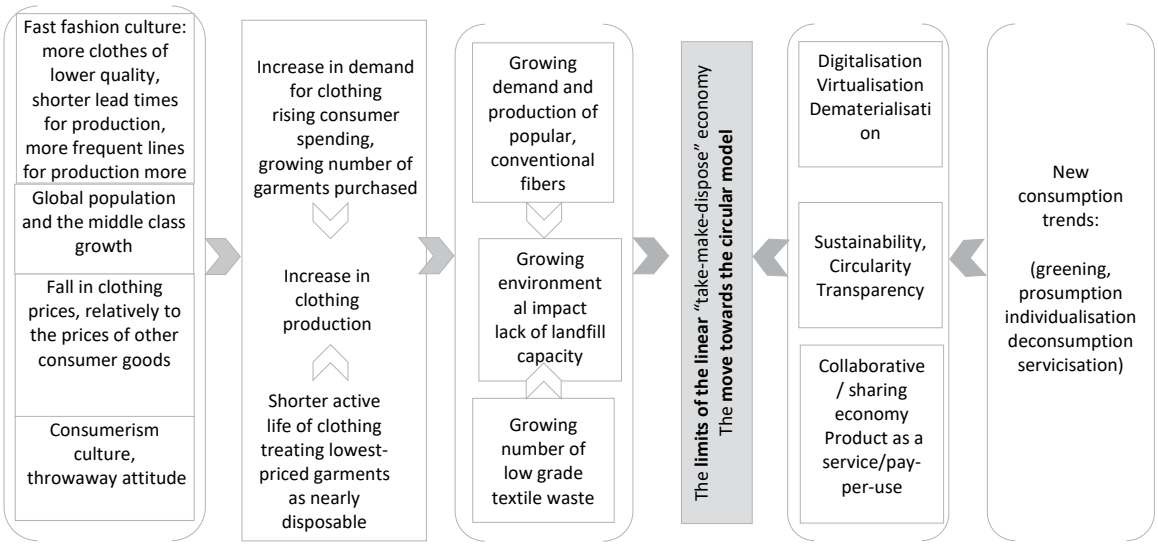
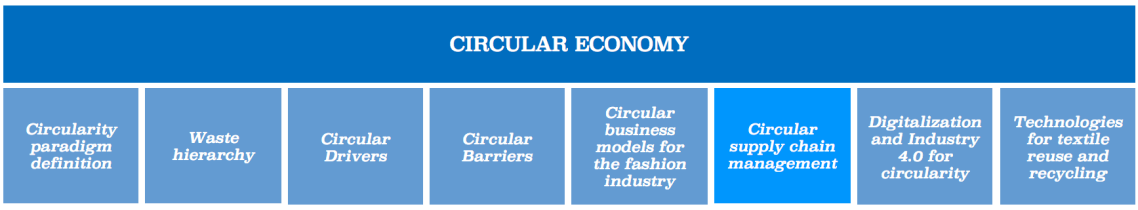


Figure. 20 - Trends in the textile and clothing industry pushing the move towards circular economy (Bukhari, Carrasco-Gallego and Ponce-Cueto, 2018)



The business model features proposed above impact manifold stakeholders across the whole value creation process and shall thus now be complemented with the theories aiming at the correct and most fitting sustainable supply chain management, adapted to closed-loop flows.

1.2.6. *Circular supply chain management*

The roots of CSCM lie in the broader field of Sustainable Supply Chain Management, thus in "*the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements*" (Seuring and Müller, 2008).

In literature, circular supply chain management is referred to as "*the coordinated forward and reverse supply chains via purposeful business ecosystem integration for value creation from products/services, by-products and useful waste flows through prolonged life cycles that improve the economic, social and environmental sustainability of organizations*" (Batista, Bourlakis, Smart, *et al.*, 2018). In addition, Farooque et al. proposed a wider conceptualisation: "*Circular supply chain management is the integration of circular thinking into the management of the supply chain and its surrounding industrial and natural ecosystems. It systematically restores technical materials and regenerates biological materials toward a zero-waste vision through system-wide innovation in business models and supply chain functions from product/service design to end-of-life and waste management, involving all stakeholders in a product/service lifecycle including parts/product manufacturers, service providers, consumers, and users.*" (Farooque *et al.*, 2019).

In these regards, the maximisation of value creation over the entire life cycle demands a much more close-knit and collaborative supply chain network which may act in unified and controllable manners over the whole productive existence of a resource. Savaskan indeed suggests that the requirement to take a holistic view of the whole product supply chain is a fundamental step for establishing greener and more sustainable production systems, based on re-using and re-manufacturing materials (Savaskan, Bhattacharya and Wassenhove, 2004). That is to say that closed loop systems are only possible if management co-operates across the entire supply chain (Lopes de Sousa Jabbour et al., 2019).

Furthermore, the complexity of the Green Supply Chain has increased from being an open-loop SC to being a closed-loop SC, from being a single SC to being a network SC, making the assumption of deterministic demand mostly infeasible (Chen *et al.*, 2019). As pointed out by Reverse Resources, global fashion brands (the buyers) play a more significant role than they imagined (Reverse Resources, 2017). Anyhow, if they don't move forwards it will be much more burdensome for other supply chain partners to effectively spur a transition towards the full adoption of circular business models.

A study about incumbents' struggles and challenges in the textile industry revealed how a firm's position in the manufacturing value chain determines the magnitude and significance of the demand pull or push, in turn dictating the willingness of supply chain partners to co-innovate for circularity. Actors upstream the supply chain (e.g., fibre manufacturers and chemical companies) succeeded in encouraging product development downstream through the provision of basic materials. Similarly, firms downstream (e.g., big manufacturers and retailers) were able to effectively pull demand for green raw materials from suppliers upstream. In contrast, firms situated in the middle of the supply chain (e.g., providers of services such as dyeing or spinning, or

garment component parts such as elastics, zippers, or buttons) reported much more difficulty in massively influencing demand for their circular products. These “in-the-middle” firms are even called “sandwich spectators”. Whilst, the influential nature of firms at the extremes of the chain could be partly explained by the fact that they are more visible and are therefore subject to stronger pressures from a wide range of stakeholders compared to firms in the middle. In these regards, the study suggests that circular policies at the industry level should target certain parts of the value chain for more leveraged results in advancing the CE. Moreover, it has to be considered that besides the position of a firm in the value chain, the relative size or power of the innovative firm versus the relative size of its supply chain partners greatly determined the latter's willingness to engage and invest in the joint innovation effort. (Franco, 2017)

Hence, currently the fashion industry lacks of confidence relating to the risk of not profiting from an investment made upstream, because the majority of benefits is received and trapped at retail level. On the other side, brands often miss the understanding and the visibility on their second and third tiers of suppliers necessary to be sure that the activities of a project of innovation or certification will be deployed correctly following their code of ethics.

Accordingly, from the operations management perspective, Matsumoto et al. (2016) suggested the integration of forward SC with RL for operations such as raw material purchasing, planning, production, marketing and distribution for realizing the sustainable potential of CE (Matsumoto *et al.*, 2016). Hence, the shift towards CE models is inevitably shaped by operations management decisions, as management of reverse cycles, cascading, and reuse and remanufacturing processes require systemic changes across a large range of areas, from product development to production and supply chain management (Batista, Bourlakis, Liu, *et al.*, 2018).

However, beyond the complexity of related change management in all business units, planning and control (PPC) in particular presents further specific challenges. First of all, Baxter and Milios point out the uncertainty regarding the quality, quantity and timeframe for return of materials and components to be remanufactured, refurbished or reused (Baxter, Aurisicchio and Childs, 2017; Milios, Davani and Yu, 2018) This uncertainty is then reflected in a higher toughness to maintain highly qualitative performances in processes and final products, which in turn affects consumer choices and indirectly then also the ability to convince banks and investors is order to raise funds (Akçalı and Çetinkaya, 2011).

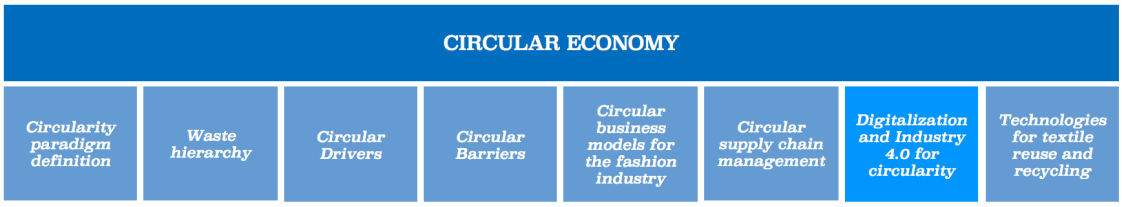
All these issues may be solved through a more conscious and deep control over each resource flow and new value creation stream. Linking to the abovementioned benefits of the sale of performance, servitization represents the operational key to gain greater differentiating factors, capitalize more on the value in circulation, keep demand thriving and create closer customer

relationships, while also maximising the appreciation of shorter loops in the system (Kim, 2007).

Furthermore, servitization reaches higher success when applied in connection with personalization and customization, since the company may perfectly adapt the experience of the product to the customer's preferences creating a win-win condition in which it's possible to maintain value even longer. In these regards, Product-Service Systems aim at solutions that decrease the environmental issues caused by intense product consumption and aims to be a competitive business model for companies that look for competitive differentiation (Beuren, Pereira and Fagundes, 2016).

Accordingly, for the sake of the facilitation and exploitation of value held in circulation, digitalization and traceability play a fundamental role. Being able to track and act on the history of materials' origins and processes and the history of customers' preferences, also permits to the service suppliers to keep rethinking, refining and readapting their offer. Particularly, user-centred design is a capability required for the sharing model, encouraging organizations to design products aligned with multiple users, as well as service orientation. Thus, close customer relationships are vital in order to design versatile products and to understand the factors which lead to product obsolescence, moving towards a reduced level of wastes or value losses (Lopes de Sousa Jabbour et al., 2019). Similarly, Walmsley et al. define 'Circular Integration' as "a holistic, need-centric approach to circular system planning where one designs, operates, and maintains every sub-system, spanning multiple-scales and dimensions, to maximise total sustainability" (Walmsley *et al.*, 2019)

A prerequisite for the achievement of overall optimal performance dimensions shall be the application of industry 4.0 systems, due to the significance of technology in carrying out environmentally-sustainable oriented operations excellence decisions. In particular, the realization of components of I4.0 is the technological foundation to enhance most of all collaboration, flexibility, transparency and dynamism across the circular SC (Dev, Shankar and Qaiser, 2020).



Given the relevance of an advanced technological foundation for the maximisation of performances related to the circular supply chain management rationale proposed in the previous chapter, the review shall now deepen the potential of single digital technologies and particularly focus on the opportunities obtainable through the establishment of blockchain architecture across a supply network as the one pertinent to apparel manufacturing.

1.2.7. Industry 4.0 and blockchain technology for circularity

'Digitalisation' generally describes the integration of digital technologies into everyday life, embodying the fourth industrial revolution. (Sarc et al., 2019) In the literature, as Tschandl et al. (2019) show, no uniform definition for the term Industry 4.0 has yet been established (Tschandl *et al.*, 2019). However, according to Sarc et al. the different definitions can be used to derive the following general definition: "Industry 4.0 describes the widespread introduction of information and communication technology (ICT) as well as its connection to an Internet of Things, Services and Data with the goal of real-time control of production and value chain networks". Autonomous objects (workpieces, storage and conveyor systems, robots and machinery and equipment), mobile communication, real-time sensors/actuators and ICT enable a paradigm shift, from once centralized controls to a decentralized, flexible coordination of self-controlling processes. As a result, from the production perspective, it is possible to react quickly, decentrally and flexibly to customer requirements and to produce large numbers of variants with simultaneously low batch sizes economically, as well as introduce new, customer-oriented business models successfully, which will further increase competitiveness. (Sarc et al., 2019) According to Li & Fung, "The application of digital technologies has the potential to reduce the time it takes to move an item through the supply chain by 48%... That means digitalization could cut up to 19 weeks of the process." (Weinswig, 2017)

In support to the efficient and effective application in circular economy initiatives, the features of digitalization connect to each of the principles of the ReSOLVE framework. framework. According to Dev et al., cyber-physical systems, IoT and cloud services enable the tracking, tracing and sharing of information related to inventory management, supply, demand across the supply chain and consumers, thus supporting improved sustainable production and optimisation decisions, reverse logistics and the customization of products and services (Dev, Shankar and Qaiser, 2020).

Consistently, digitalization is required to follow and act on the products throughout their life cycle and especially through the use and end-of-life stages, where otherwise the ability to choose among valuable alternatives is lost. Unfortunately, the comparison of waste management with other industrial sectors shows that digitalisation and the use of robots in circular economy and waste management are still in their infancy. However, as more and more technological applications are developed, digitalisation in waste management is estimated to be relatively high in the future. (Sarc et al., 2019)

The fashion industry, in particular, will require the full exploitation of RFID tags on garments, genetic markers on the fibres and sorting technologies in order to truly implement closed loop, preparing the garments for reuse or recycling. The reason of the criticality for clothing stays behind the fact that there are no components to be tracked singularly and easily de-manufactured. The common extensive use of blends and aggressive finishing or dyeing chemicals poses large threats to the ability to extend the life of resources, leading to the extreme impacts of the current state. In this sense, there are already some pilots striving to scale, as the case of Primo1D which works on embedding electronics in textiles using the E-ThreadTM yarn, which contains RFID threads. Then when blockchain technology is combined with upstream innovation as the use of DNA in plant-based materials to geo-locate their origins, this will contribute to full end-to-end value chain traceability (Lehmann *et al.*, 2018). Consistently, genetic markers or coded yarns, since they cannot be removed or copied, provide higher security against counterfeiting and ensure also proper care, recycling and return for the whole length of the material life cycle (Sustainable Brands, 2017).

Accordingly, despite the few direct labelling requirements, companies seeking a competitive advantage are increasingly disclosing voluntary environmental impacts of garments directly onto labels (Lehmann *et al.*, 2018). IoT devices (collecting data that connect to the internet) embedded in garments will thus interface with users to tell the story of a product, its provenance and impact, and provide consumers with the necessary information for responsible care and disposal (Project Provenance Ltd., 2015). Beyond this, the few labelling requirements under regulation, as in the case with organic labels, would be streamlined in a blockchain system that could store certificates of inspection on the ledger (Rusinek, Zhang and Radziwill, 2018).

Hence, in addition to the enabling digital technologies, a key success factor of the circular revolution initiative will be the effectual usage of the information that can be recovered and shared. “Big Data” is indeed a fundamental element of digitalisation and already a valuable raw material for many industries. In combination with “Artificial Intelligence”, it is possible to structure, analyse, evaluate and use large amounts of data as a basis for software programs that can generate new (or extended) knowledge with the technology of “Machine Learning”. From this, future forecasts can be derived as well as used in

optimization measures. Often "Deep Learning" is used, which is based on the human brain and uses artificial neural networks to mimic the learning processes of humans. This makes it possible to use data volumes meaningfully across the entire value chain. For instance, robotic systems can learn from experience and can thus sort more efficiently (Sarc et al., 2019).

Despite some possible drawbacks as the greater space requirements, additional costs due to necessary structural facilities and security measures against cyber-attacks, generally industry 4.0 is seen as the main game changer also for the circular fashion sector. Competition is promoted and labour productivity increased, which in principle benefits the consumer. (Sarc et al., 2019)

BLOCK CHAIN TECHNOLOGY

Don & Alex Tapscott defined blockchain as "an incorruptible digital ledger of economic transactions that can be programmed to record not just financial transactions but virtually everything of value." (Tapscott and Tapscott, 2016). According to Di Gregorio (PwC): "Blockchain may have a long-term influence on the global economic system, reshaping market structure, customer experience and product features. Indeed, according to the PwC 2016 FinTechreport, blockchain-related interest and investment have reached critical mass, and the technology has shown itself to be capable of driving major change" (Gregorio, 2017). In particular, the Gartner Hype Curve (in Figure 21) shows how this emerging technology just passed the 'peak of inflated expectations' and is directed towards the 'plateau of productivity' in 5 to 10 years from 2018 (Panetta, 2018). Accordingly, IDC experts further forecast an outstanding five-year compound annual growth rate of 76.0%. (IDC, 2020)

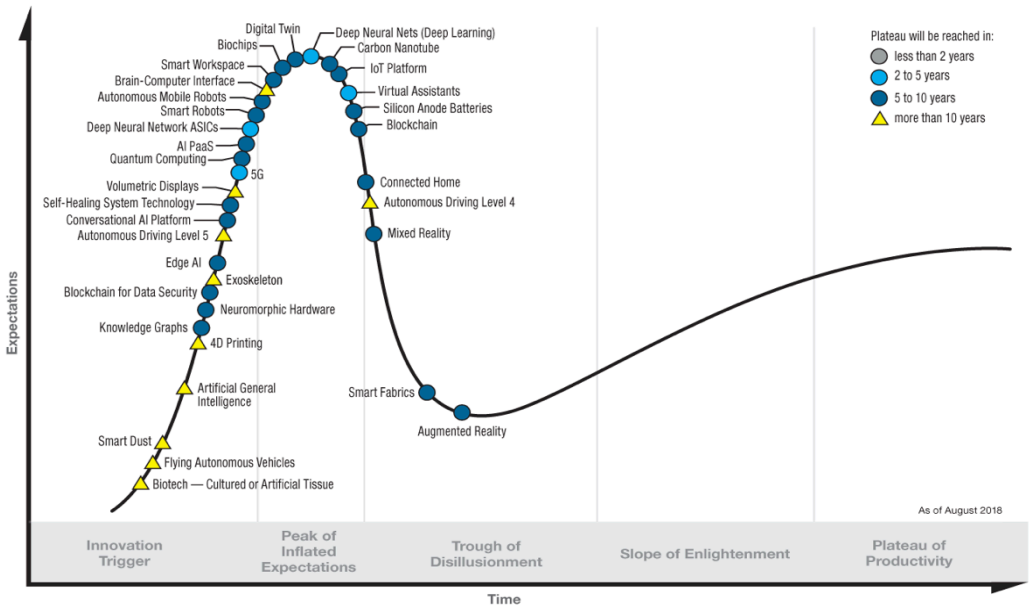


Figure. 21 - Hype Cycle for Emerging Technologies, 2018 (Panetta, 2018)

In these regards, the European Commission has already started developing a strategy to create a common approach to blockchain for the entire European Union, through the following initiatives (*Eu Blockchain Observatory and Forum*, 2020; *International Association for Trusted Blockchain Applications*, 2020; EU, 2020a, 2020d, 2020b, 2020c):

- European Blockchain Partnership (Apr 2018)
- EU Blockchain Observatory and Forum (Feb 2018)
- International Association for Trusted Blockchain Applications (INATBA) (Mar 2019)
- Horizon Prize on Blockchain for Social Good (i.e., 5M€)
- Financing blockchain and distributed ledger technologies research and innovation projects (i.e., 340M € is the budget to be invested by the end of 2020).

The blockchain technology represents indeed the missing element necessary to not only enhance the full adoption of circular business models but also provide confidence and security to the supply chain. It seems that inefficient transactions, fraud, pilferage, and poorly performing supply chains, lead to greater trust shortage, and therefore, a need for better information sharing, and verifiability (Saberi et al., 2019). The problem originates from the fact that current supply chains rely heavily on centralised, sometimes disparate and stand-alone information management systems, that are within organisations; for example, enterprise resources planning systems, which has its own pitfalls (Abeyratne and Monfared, 2016). Single point failure is a disadvantage of centralised information systems which leaves the whole system vulnerable to error, hacking, corruption, or attack (Saberi *et al.*, 2019). Furthermore, diverse stand-alone systems in a silos mode across different companies, may eventually drive friction up and transparency down.

On the other hand, block chain technology (also known as distributed ledger technology) is essentially a peer-to-peer distributed asset database that can be shared across a network of multiple sites, geographies or institutions and is updatable only through peer consensus (Brown, 2016; Bashir, 2017) The technology's core innovation lies in its ability to publicly validate, record and distribute transactions in immutable, encrypted ledgers (Swan, 2015).

The interconnectivity and interoperability among block chains is still being studied, but already now the promised potential is huge especially when applied to industrial supply chains. If integrated with field-sensing technologies such as the Internet of Things (IoTs), block chains could create permanent, shareable and actionable records of products' digital footprints throughout the entire supply chain (Wang et al., 2019), enabling real-time tracking and controlling.

Furthermore, because all data recorded within a block chain is distributed among all network members, records of transactions and activities are open for every permissioned member to access, unlike in the traditional method of utilising a third party. Each participant can check the progress and location of the products and can share the same information within the system (Kim and Laskowski, 2016).

Hence, the key attributes and claimed benefits of block chains may be summarised as follows (Yli-Huumo *et al.*, 2016; Iansiti and Lakhani, 2017; Manav Gupta, 2018):

- *Disintermediation*. Because block chains are peer-to-peer networks, they reduce reliance on third parties.

- *Transparency with pseudonymity*. The information within block chains is viewable by all participants and cannot be altered by a single entity, thus creating trust and reducing fraud. Users can choose to remain anonymous or provide proof of their identity to others.

- *Automation*. Block chains can be programmed to automatically trigger actions between nodes (such as payments or other events) once certain conditions are met. In order to permit this mechanism there are smart contracts, which are entirely digital and are written using programming code languages, still with the same rules and consequences as a traditional legal document would, stating the obligations, benefits and penalties. The contracts can be automatically executed by a block chain system, thus leading to high levels of automation and streamlined supply chain processes.

- *Security*. Various computational algorithms and approaches are deployed to ensure that the recording on the database is permanent, chronologically ordered and available to all others on the network. Block chains' distributed and encrypted nature makes them difficult to hack.

Specifically, as shown also in figure 22, the technical features enabling these general properties rely on asymmetric cryptography principles in order to avoid sharing of confidential keys combined with transactions automation, in order to lean up the process of verifying a condition and auctioning relative consequences. In these regards, a smart contract is a software program that uses blockchain to execute an agreement. No fraud or other interference is possible. A smart contract can take input from a ledger and trigger an event. For example, after receipt of a payment as part of a transaction, the smart contract can trigger a delivery. Conversely, if a requirement (such as timely delivery or proper storage) is not met as expected the smart contract can trigger a penalty or similar sanction (O'Byrne, 2020a). Basically, it is a program

or transaction that will be executed upon validating nodes, which will provide or not the related consensus.

The problem lies in the inalterability characteristic of blockchains, which represents a double-edged sword because on one side it grants the necessary advanced security but on the other it poses limitations for well-aimed modifications. Indeed, once a smart contract is written into a blockchain, it's impossible alter it, denying the possibility to correct any bugs that were not discovered before. Hence, writing smart contracts is likely to be the biggest and the most complex step. (O'Byrne, 2020b)

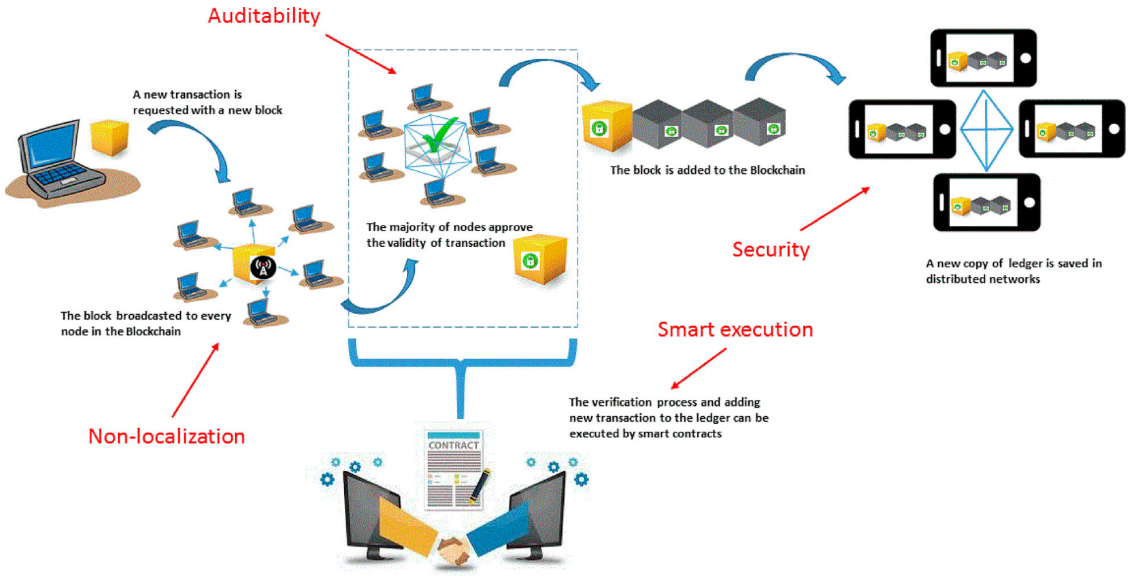


Figure 1. Steps in blockchain information and transactions.

Figure. 22 - Steps in blockchain information and transactions (Saberi et al., 2019)

Nevertheless, beyond the resolution of these technical issues, the automation capabilities may be particularly exploited within value chains. Blockchain allows indeed to create a virtual single shared pool of data among all the authorized players in a particular supply chain ecosystem, who are then able to see everything that's relevant to them and that they are authorized to see as soon as a change takes place. In particular, blockchain also eliminates huge amounts of time and effort spent continuously reconciling internal records—for instance, matching up invoices, receipts, and purchase orders to determine whether your business needs to pay a particular invoice. Basically, this technology allows to replace the vast majority of human intervention with relatively simple AI capabilities. (Oracle Supply Chain Management, 2019)

Additionally, blockchains can play an important role in stolen merchandise recovery and in avoiding fraudulent transactions (Apte and Petrovsky, 2016; Loop, 2017). For what regards fashion, especially for the luxury segment, this may also be used in the field of counterfeit goods since the falsity becomes easier and more standardised to be checked. In the same way exact quantities and movements of flows may be traced to avoid the problem of burden shifting, in the case of textile brokers profiting on exporting used garments to already over-saturated developing markets with lower end-of-life management infrastructure.

Additional efficiency can be gained through the digitalisation of document transfers and the acceleration of the flow of data, particularly in the context of cross-border activities (Barnard, 2017). In fact, for customs authorities, the solution is intended to provide real-time visibility, thus significantly improving the information available for risk analysis and targeting, which could eventually lead to increased safety and security as well as greater efficiency in border inspection clearance procedures. (Wang et al., 2019) Furthermore, generally all types of firms will have the possibility to reduce the need for manual intervention in aggregating, amending and sharing data, and regulatory reporting and audit documents could become easier, requiring less manual processing. As a result, employees could focus exclusively on value-added activities. (Gregorio, 2017)

Another benefit is the accelerated tracking block chains afford, which often reduces the tracking time from origin to completion from days to minutes (Bedell, 2016; Kharif, 2016). Hence, not only can efficiency be gained through removing wasteful activities from the supply chain; efficiency can also be achieved via preventive measures. (thanks to accelerated tracking) (Wang et al., 2019)

Furthermore, blockchain and the database systems can be a relevant marketing and branding tool if companies able to extract the insights from the data (Fashion Technology Accelerator, 2020). The improved data visibility provides supply chain actors with an in-depth understanding of what consumers want as well as showing the demand for particular products (Wang et al., 2019). If combined with a rental system, block chains may also minimize the issues of lack of traceability during the use stage. Today, retailers have little or no insight on what happens to garments beyond the point of sale, with little understanding of how often an item is worn, in what conditions it is used nor what customers think about it (Accenture Strategy & Fashion For Good, 2019).

Thus the business model works as an enabler of data accessibility and the digital technology acts as an effective mean of value extraction. Furthermore, according to Tess Kornfield from the thredUP's Lead Data Scientisty, "by mining thredUP's unique trove of data, it is possible to help guide purchasers toward clothes that can be resold rather than discarded—a mind-set shift that

is good for wallets and the planet." (Thred Up, 2019) On the side of loyalty programs management, it would be possible to enhance security and trust, reduce frauds, analyse the performance of loyalty systems in real-time and thus generally boost the value of such programs, particularly important for luxury and fast-fashion brands. Finally, smaller "challenger" brands may be also interested in blockchain applications aimed to protect their brands and to ensure traceability to demonstrate commitment in ethical and environmental issues. In this case, the applications aimed to enhance user engagement could be explored either to tap into collective intelligence (e.g., crowd design) or to experiment with new fundraising avenues (e.g., crowdfunding) (Pautasso, Ferro and Osella, 2019). Hence, it goes without saying, that customer centricity will be a critical key for future success.

All the benefits together, may optimally induce the full adoption of circular economy principles, by supporting the optimisation of end-of-life alternatives management, reverse logistics optimisation, servitization developments, customer-centred design and value maximization within reuse models thanks to digitally-advantaged users.

In these regards, the review shall now include the determinants for the evaluation of which players and individuals will have visibility over the great amount of valuable data tracked. As Wang et al. elucidate, there are two types of block chains, based on the access control mechanism involved (i.e. who can read a block chain, submit transactions to the block chain and participate in the consensus process) (Wang et al., 2019):

- ***Public block chains***. In this type, every transaction is public (and hence 'permissionless'), and users can remain anonymous; the network typically has an incentivising mechanism to encourage more participants to join the network. Bitcoin is a typical example.

- ***Permissioned block chains***. In this type, participants must obtain an invitation or otherwise have permission to join. Access tends to be controlled by a consortium of members (consortium block chains) or by a single organisation (private block chains).

Gupta (2018) pointed out that 'permissioned' block chains are of particular value to businesses, as they offer enhanced privacy (because access to transactions can be determined by users' roles/responsibilities), auditability (since a shared ledger that serves as a single source of truth improves the ability to monitor and audit transactions) and increased operational efficiency (as transactions can be conducted at a speed more in line with the pace of business) (Manav Gupta, 2018).

Furthermore, another possible option may emerge from the combination of the two above-mentioned block chain types. According to a Cognizant Report, the consortium provides indeed a hybrid between the public and private models. It

is of particular interest because while supply chain partners may want full transparency, the fact of the matter is that a majority of participants are competitors. For instance, manufacturers A and B may not want the selling price of a shirt, or their relationship with producers to be revealed through transactions on a common network. (Patel *et al.*, 2018) Basically, this decisive alternative merges the benefits of the other two such as the privacy, trust and operational efficiency of a permissioned chain together with the flexibility and accessibility from large customer bases of a permissionless chain.

The enhanced visibility on operations and processes that once lied in a hazy grey area may be exploited also for supporting financial funding activities. According to Chod et al., at present normally firms seeking the capital needed to efficiently run their operations are often impeded by the vexing problem of information asymmetry. Unable to readily ascertain their fundamental operational capabilities and gauge their risk, prospective lenders frequently command prohibitively high financing rates, which lead to operational distortions (Chod *et al.*, 2018). In respect to this, an important benefit of blockchain adoption stays in opening a window of transparency into a firm's supply chain and furnishing the ability to secure favourable financing terms at lower signalling and monitoring costs than traditional methods on inventory transactions' checks.

Block chain architecture applied to supply chains has indeed also the potential to enhance partners' confidence levels. Gaehtgens and Allan even state that it 'programmes' the much-needed 'trust' in digital systems (Gaehtgens and Allan, 2017). The transparency achieved in block chains may thus revolutionise how we understand and research trust in supply chains (Field, 2017) Previously, intermediaries and mechanisms such as banks and stamped documentation had to act as a critical conduit of transactions between organisations. Trust among these supply chain actors tended to be low due to the lack of transparency and visibility, particularly within multi-tier supply chains (Grimm, Hofstetter and Sarkis, 2013; Kembro, Näslund and Olhager, 2017). However, this business of trust is about to be disrupted and transformed with the advent of blockchain technology. (Matthlas Heutger, 2018)

The intrinsically higher levels of confidence among supply chain partners may even be transferred further, to the users or to new stakeholders as this technology also facilitates the process of certification. Especially in fashion, eco-labels play a key role for the sustainable development of the industry and may even spur more innovativeness, thanks to the enhanced ease of processing requests.

Eco-labels are indeed used by companies to guide consumers towards more environmentally responsible products (Caniato *et al.*, 2012). Specifically, the International Organization for Standardization (ISO) has structured and classified ecolabels into three types: Type I (ISO 14024) includes broad-based third party certified ecolabels such as the EU Ecolabel and the Swan; Type II

(ISO 14021) ecolabels are self-declared environmental claims and Type III (ISO 14025) ecolabels are environmental product declarations in which quantified environmental information is presented. The Type I ecolabel criteria, according to the standard, should: i) include environmental impacts from the product's entire life cycle, ii) be established by a labelling organisation after consultation with several different stakeholder groups, and iii) use quantitative environmental information based on Life Cycle Assessment (LCA) (Clancy, Fröling and Peters, 2015). Ecolabel significant references are shown in figure 23.

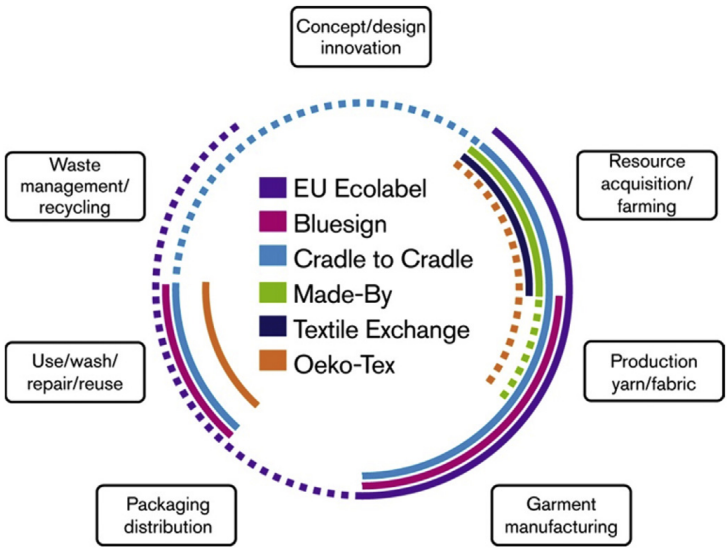


Figure. 23 - The life-cycle stages covered by 12 ecolabels investigated (Clancy, Fröling and Peters, 2015)

Accordingly, the general process steps of blockchain application in the fashion supply chain will be the following ones (Patel *et al.*, 2018):

1. ***Agent On-boarding & Registration*** - All participants are on-boarded and registered. They will be provided with a public/private key to reflect their digital identity on the blockchain by a registry. Furthermore, records will be available for inspection on the blockchain by the entire community.

2. ***Asset Registration*** - A token or digital identity is created for each asset.

3. ***Asset Certification*** - The on boarded certification authority will inspect and verify the asset and provide a certification for the asset in adherence to best practice standards. In particular, specific attributes such as fair trade and fair labour certificates can be achieved.

4. ***Transaction*** - Transfer must require both parties involved to sign a digital contract.

5. ***Certification & Tracking Through Smart Contracts*** - Digital signature and authorization is required to validate and execute terms of contract.

6. ***Audit*** - Independent auditors can audit the flow of materials through manufacturing tiers. This additional layer provides a greater level of creditability and verification of the processes.

Beyond these phases, the retailer will then be able to access the blockchain to verify the origin of each input used in manufacturing. Industry regulators may inspect, spot-check data and verify the entire lifecycle process using the digital ledger. Finally, consumers will gain the opportunity to view a product's entire journey details and certification from field to shelf via QR codes or apps, enabling more informed purchase decisions. (Patel *et al.*, 2018)

In these regards, four inputs predominantly impact the costs of both public and private blockchain solutions and depend entirely on the use case and objectives an organization aims to accomplish (EY, 2019):

- ***Transaction volume requirements*** determine the scalability characteristics a blockchain solution should possess for particular use cases, where the large majority falls under the 365,000 annual transactions mark (1,000 transactions per day).

- ***Transaction size*** refers to the storage requirements for one unit of value transacted on the network. Transaction size primarily impacts, among others, transaction review and audit costs. As an example, applications that require the use of smart contracts to execute agreements based on programmable conditions result in a larger transaction size than applications that facilitate the transfer of value, such as payments or securities.

- ***Node hosting method***. The three most common stand-alone methods are on-premises (new systems), on-premises (existing technology) and cloud-based. This input is less material for public blockchain software but is critical in costing private blockchains.

- ***Consensus protocol*** refers to the method of verifying the legitimacy of blocks of transactions. The following consensus protocols are utilized by both public and private blockchains:

    - *Proof of work uses a large amount of computing power to mine blocks of transactions.*

- *Proof of stake uses financial assets as an incentive to mine blocks with integrity.*
- *Proof of authority allocates the responsibility of verifying blocks to specified participants.*
- *Byzantine fault tolerance employs a voting system, usually within private blockchains, through which consensus is met once identical responses are received from trusted nodes.*

In particular, the type of consensus protocol used depends on an organization's current situation and objectives. Each option offers different levels of decentralization, security, power consumption and hardware requirements. Participants in a public blockchain may use proof of work to ensure that blocks (and, therefore, transactions) are verified with computational integrity rather than based simply on authorized permission. However, a computationally intensive consensus protocol, such as proof of work, results in higher electricity costs, higher hardware costs and greater processing times for transactions executed on the system. Additionally, in comparing transaction costs, use cases with very high transaction volumes are often well-suited for private blockchains, as high fixed costs are averaged out across a larger number of transactions. Use cases with more complex assets and transactions, as well as low-to-moderate volume, are well-suited for ZKP software. Ultimately, the substantial costs of training, audit and technical support highlight the importance of appropriate governance processes and practices, particularly as it relates to private blockchains (EY, 2019).

Generally, if not organised correctly, hurdles may arise in the implementation of change management policies since there are wide skills gaps present in traditional businesses as shown in figure 24.

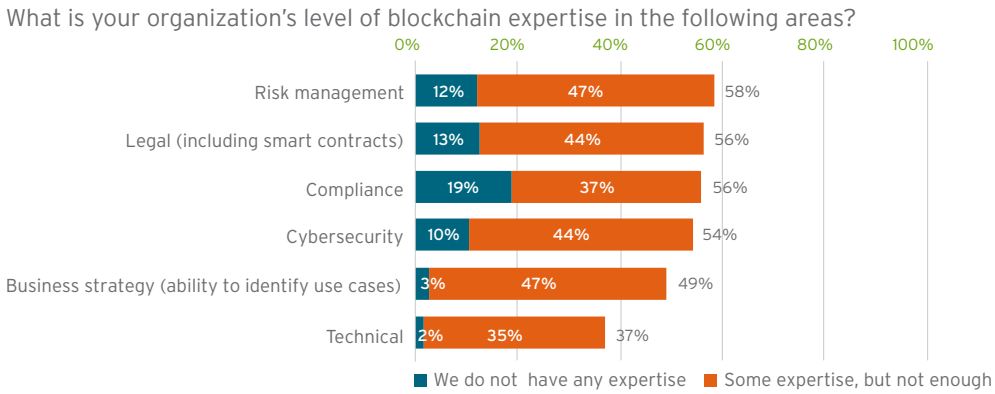


Figure. 24 - Blockchain Skills Gaps (Weldon, Herridge and Cohen, 2017)

In connection to this, there are several barriers hampering the expansion and effective implementation of such a promising technology.

As stated in a recent Cognizant report, blockchain problems may be classified as follows (Patel et al., 2018):

- Ecosystem Challenges
    - *Regulatory uncertainty and perceived legal risk*
    - *Data protection laws vary across geographies*
    - *Implementing evolving blockchain platforms*
    - *Interoperability between platforms and lack of standards*

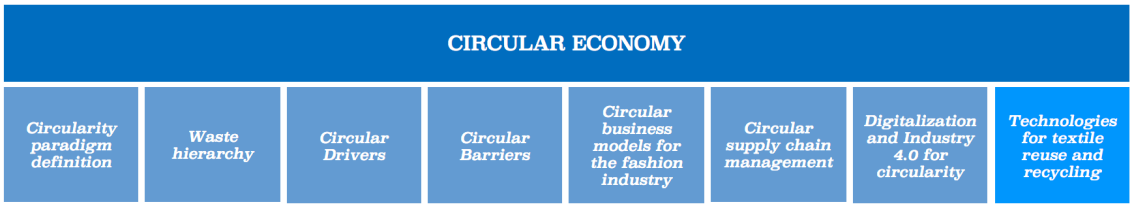
- Business Challenges
    - *Providing participants incentives to perform best standard practices*
    - *Need for ground audits and recertification to ensure real world compliance of best practices*
    - *Increased cost to the supply chain for producers and the consumer*

- Industry Challenges
    - *Providing incentives to each supply chain partner for agreement to board onto the network*
    - *Each player has their own unique way to map the supply chain. Reluctance of these players to share these details can possibly hamper the formation of a consortium*

Solutions shall thus be drawn from the virtuous combination of accurate technical design features and regulative background development. Contrarily, naively implemented blockchains are arguably the worst performing, most expensive, and least sustainable supply chain databases ever (Evrythng, 2018). Thorough and specific analysis shall be carried out because convenience widely depends on the configuration of each chain of actors and technical requirements for the tracking of related product flows. According to O'Byrne (2020), many blockchain platforms are open source technologies that are free to use. If there is a cost issue, it is more likely to be in the engineering resources required to make the platform do what is demanded. Besides, as blockchain solutions multiply, ease of use is also improving. In particular, it will be crucial to support not technically minded users through the development of a well-aimed interface, which can make it simple for participants to ask for admission

to the system, enter transaction requests or confirmations to update the ledger and trigger execution of smart contracts (O'Byrne, 2020b).

As for any digital technology with widespread disrupting impacts, great work has to be done to improve systems' design and agents' mind-set. Once the transitory phase is ended, the critical and advanced visibility enabled may then actually revolutionize the way business collaborate and co-innovate, the way regulations are implemented and the way consumption patterns evolve. Furthermore, as widely acknowledged, it would benefit the optimal development of end-of-life management options, also by partly solving the problem of not knowing the contaminations of post-consumer waste occurred during the use phase, thus providing informational support during testing as well as textile reuse and recycling processes.



In connection with the digital layer provided by field-sensing technologies integrated with blockchain deployed above, the proper initial propelling and steady state functioning of the desired closed-loop system will strongly depend on the development of effective and efficient recycling and sorting technologies. The subsection dedicated to circular fashion shall thus be concluded with an overview of the key innovations enabling the higher effectiveness of the framework to be proposed, considering the relative potential growth drivers and operational hurdles.

1.2.8. *Textile reuse and recycling*

Once pre- and post-consumer waste is collected, manual selection processes separate the percentages of products to be reused, while a second step through automated sorting will be possible in the near future in order to facilitate fabric and fibre recycling. Still, the development of these and other reuse and recycling related technologies relies on the efficiency of the whole reverse supply chain, which in turns depends on the optimisation of collection infrastructure and on the expansion of a valuable end market to close the loop. Currently, there are manifold hurdles that obstacle the realization of the huge potential value present in higher scaled collection, sorting and recycling businesses.

First of all, there is a lack of standardization in terminology that further worsens the issues related to green-washing and fraudulent transactions, while also blurring the current state statistics and therefore misleading the future projections.

Textile reuse refers to various means for prolonging the practical service life of textile products by transferring them to new owners, with or without prior modification (e.g. mending) (Fortuna and Diyamandoglu, 2017).

Textile recycling, on the other hand, most often refers to the reprocessing of pre- or post-consumer textile waste for use in new textile or non-textile products. Textile recycling routes are typically classified as being either mechanical, chemical or, less frequently, thermal. This is in many cases a simplification of reality, as recycling routes often consist of a mix of mechanical, chemical and thermal processes. To complicate things further, incineration with energy recovery is occasionally labelled as recycling, although the term recycling most often refers solely to material recycling (as is the case in the present paper). (Sandin and Peters, 2018)

The missing standardization then affects also the methodologies to assess environmental performances and compare alternative life cycles, since many aggregate assumptions and estimations has to be entered. Generally, Sandin and Peters claim that a multitude of researches supports textile reuse and recycling to reduce environmental impact compared to incineration and landfilling, and that reuse is more beneficial than recycling. There are however studies that do expose scenarios under which reuse and recycling are not beneficial for certain environmental impacts. For example, as benefits mainly arise due to the avoided production of new products, benefits may not occur in cases with low replacement rates or if the avoided production processes are relatively clean. Also, for reuse, induced customer transport may cause environmental impact that exceeds the benefits of avoided production, unless the use phase is sufficiently extended (Sandin and Peters, 2018).

Hence, this highlights the need for more solid assessment procedures for the evaluation of concerns, in which the cases under investigation may be widely different among each other. As Sandin and Peters (2018) state, the potential stumbling blocks serve as a reminder that analysts of the environmental impact of textile reuse and recycling should adopt a life cycle perspective, consider collection and sorting processes, consider all relevant impact categories, and clearly describe and motivate key methodological choices and assumptions (Sandin and Peters, 2018). In these regards, Life Cycle Assessment (LCA) is an environmental assessment method, which may assist in identifying opportunities to improve the environmental performance of products, inform decision makers, select environmental indicators of environmental performance, and support marketing statements (ISO, 2016). As a matter of fact, LCA analysis is typically used to look at product chains as well as user

behaviour (Blomsma, 2016), an may thus valuably verify the prioritisation necessary among diverse end-of-life strategies.

Accordingly, on average literature strongly supports the waste management options preferred according to the waste hierarchy, as promoted by the EU directive on waste (European Parliament and Council, 2008). Anyhow, concrete application of the superior waste management strategies within the hierarchy are presently extremely limited due to further stumbling blocks both in the perspectives of supply and demand. Regarding the latter, the expansion of a valuable end market of fibre-to-fibre recycling is affected by the possibility of establishment of a "market for lemons". As Massarutto specifies, the reason lies in the fact that quality of recycled materials is often difficult to assess ex-ante. This distorted situation arises when better-than-average quality products are excluded from the market because nobody is willing to pay more than an average price, taking into account the risk of buying low quality (Massarutto, 2014). The fashion market is indeed maybe willing to follow the circular and sustainable trends, but is still not ready, in terms of technical knowledge and solid supply chain relationships, to accurately value and differentiate each offer of closed-loop inputs. In turn, this limits the rise in usage of such preferable alternatives.

Furthermore, on the supply side, collection, sorting and recycling of textiles suffer from severe system costs and inefficiencies. These infrastructural pitfalls originate from the following technical characteristics:

- *Sorting of textiles is very expensive and it is time and labour intensive* (Sherburne, 2009)
- *The use of different fibre blends has further made clothing difficult to sort and recycle* (Hawley, 2009)
- *Quality of collection and the demand for used clothing are not always the same and the price of used clothing is fluctuating. Only 30–40% of the collected materials can cover the recycling cost (recycling expert, 2017, personal communication) (Bukhari, Carrasco-Gallego and Ponce-Cueto, 2018)*
- *The mechanical recycling system cannot close the materials loop and it diminishes the fibre length and strength* (George, Bockarie and Mcbride, 2006)

Summarizing, the practical and economic viability of textile and clothing recycling depends on many factors, as shown in figure 25. Generally, these include the availability of appropriate infrastructure, the type of textile product and its physical condition, the degree of wear, fibre composition, finish, garment construction, logos and emblems, accessories, the manner of labelling, and, last but not least, how the garment has been disposed of (Durham *et al.*,

2015). Anyhow, the lack of up-scaled efficiency in collecting and sorting textile and clothing waste is probably the most complex problem. Due to this, low-quality materials and blends dominate in the recycling market and puts a strain on the commercially viable recycling technologies for low-grade textiles and blends (Bukhari, Carrasco-Gallego and Ponce-Cueto, 2018).

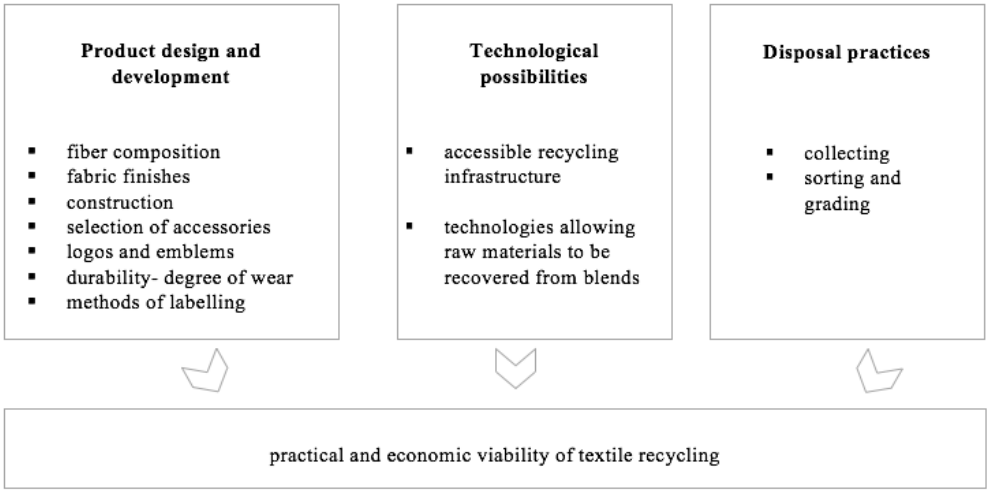


Figure. 25 - Main factors likely to influence the practical and economic viability of textile and clothing recycling in the future (Durham et al., 2015)

Hence, the determination of technologies to be employed and the whole infrastructure to be designed shall comprise a delicate balance of diverse features that bring overall economic and environmental value at the same time. If businesses and policymakers will be able to effectively cooperate and carry out step-by-step improvement programs in order to solve or limit all aforementioned barriers, it will be actually possible to fully capitalize on the higher value in circulation and assure a more sustainable future. Against the current obscure ecosystem, there are indeed innovative solutions on the way under development in these present years. Automation of sorting and discovering of new technologies for textiles recycling, e.g. chemical recycling, have been given more attention recently and developed systems are expected to shine in the near future. (Girn *et al.*, 2019) These chemical recycling technologies promise much higher performances in output quality, system effectiveness and environmental sustainability, being able to fulfil the present great improvement margins, linked to the low closed-loop recycling rates.

Additionally, the growing demand for environmentally-manufactured garments combines with rising feedstock levels, due to fast fashion volumes growth, inherently stimulating the scaling up of the reverse supply chain systems. According to Reverse Resources, it will soon be technically possible to recycle at least 80% of all textile leftovers of any solid or mixed fibre compositions commonly used in fashion industry (Reverse Resources, 2017). Furthermore, merchants may be willing to support recycling, given that a

number receive only £100 per tonne for wiping cloths derived from cotton recycling grades (Girn *et al.*, 2019).

As concrete promising example developed in collaboration with Circle Economy and Recover, the ReBlend project shows that through high value recycling, quality textile products and environmental benefits can go hand in hand. Circle Economy performed indeed a Life Cycle Assessment on one of the 100% recycled yarns (White Cream) displaying a decrease in energy use by 33%, a reduction in water consumption by 62%, and a decrease in greenhouse gas emissions by 18%, in comparison with virgin yarn of similar composition (Circle Economy, 2017). Particularly, many risks associated with chemicals in textiles may be avoided by reducing superfluous consumption of textiles in the first place, especially those with unnecessarily dangerous chemicals (Assmuth, Häkkinen and Heiskanen, 2011)

Finally, the impact analysis that was performed shows that a recycled denim fabric with only 12% recycled content already has a much lower environmental impact than its virgin equivalent: water consumption can be reduced by 9,8%, energy consumption by 4,2% and CO2 emissions could be cut by 3,8%. Moreover, costs of alternative scenarios like incineration or down cycling can be avoided when applying the high value recycling scenario, effectively reducing this price disparity slightly. Other aspects also can contribute to making recycled denim more competitive compared to virgin: (1) Growth of market pull for recycled resources and upscaling of mechanical recycling processes and (2) forecasted future price rises for virgin cotton (2025). Alternatively, recycling of denim goods into non-denim, knitted fabrics for products like beanies, scarves, and sweaters can provide a more commercially attractive option on the short term. This due the fact that % recycled in these fabrics can be much higher than in denim fabrics, making it more cost effective (Circle Economy, 2016).

Hence, even from the worsening current state it is possible to extract high value and radically change the economic and environmental performances. Since economic convenience is still the main decision driver, it shall be necessary to develop a structure of economic benefits in such a way that for each supply network player the strategy of shifting to circular economy would be preferable in contrast to a business-as-usual pursuance.

Reverse Resources conclude that the recycling market would benefit in various ways from open and transparent marketplace of production leftovers (Reverse Resources, 2017):

- *Skipping intermediaries from the trade schemes and setting up one-on-one transactions between factories and recyclers would be easier. It would bring down costs for recyclers and increase earnings for suppliers.*

- *Trustworthy and regular background information about cutting scraps from production (including information on chemicals) means less need for testing the input materials.*

- *Lowering lead times: with some recycling technologies recyclers have fluctuations in the need for a certain colour or composition at a certain time and they are sensitive to location. Higher transparency enables more efficient planning.*

- *Increasing the percentage of materials being recycled for new yarns (increased system efficiency).*

- *Tracking leftovers from factories to recycling would enable transparency of circular material flows it would be possible to measure the % of their production leftovers being upgraded to new yarns in comparison to down-cycling or dumping, giving significant insight into progress towards circularity.*

Specifically, their research also indicates that more than a quarter of the production leftovers are fabric pieces bigger than 18 inches (0.5 yards) which could still be usable in the factories, without recycling. Thus, waste hierarchy suggests that recycling (to make new yarns) should only be applied on smaller cutting scraps, yarn waste and such leftovers which cannot be reused as fabrics, products or product details. In connection to this, further research will be needed into using the pricing scheme as a fair incentive to always favour the waste hierarchy for each type of leftover; the lower the solution found for each leftover in the hierarchy, the less suppliers will earn, and the more cost-efficient it should be for buyers. (Reverse Resources, 2017)

In summary, the transition towards greater closed-loop circularity in fashion shall be economically optimised in order to pull automatic influences and gain the highest environmental gains. An increased efficiency in waste management, thanks to a greater scale of all infrastructures needed in the reverse supply chain, indeed also reduces garment producers input costs, rising the potential competitiveness of recycled fibres against virgin fibres, still maintaining same quality performances thanks to the new technologies under development. Finally, the amelioration of the management of all unexploited excesses represent a crucial priority for the fashion industry.

1.3. EXCESS MANAGEMENT

The prevention of waste throughout a product life cycle and the elimination, or at least minimization, of the percentage of waste ending up in landfills are one of the biggest challenges that the textile and clothing industry will have to confront while transitioning to the circular economy (Koszewska, 2018). Given the high value extractable from fashion waste in the near future, with the support of innovative technologies and an expanded scale in the end-of-life infrastructures, this problem actually represents both the biggest challenge and a fundamental opportunity. The whole ecosystem of stakeholders shall shift aggregately and coherently to advance both the implementation of business models and concrete measures, but also the establishment of a standardized and constructive regulative framework.

As mentioned earlier, according to Directive 2008/98/EC "waste" means any substance or object which the holder discards or intends or is required to discard (European Parliament and Council, 2008).

Particularly, according to Article 6 waste (European Parliament and Council, 2008) can be considered to have ceased to be waste if: "(a) the substance or object is to be used for specific purposes; (b) a market or demand exists for such a substance or object; (c) the substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products; and (d) the use of the substance or object will not lead to overall adverse environmental or human health impacts".

More generally, the Directive (European Parliament and Council, 2008) establishes, among other things, that Member States should make use of *economic instruments and other measures to provide incentives for the application of the waste hierarchy*, such as charges and restrictions for the landfilling and incineration of waste, 'Pay-as-you-throw' schemes for waste producers, sustainable public procurement to encourage better waste management and the use of recycled products and materials, fiscal measures to enhance recycle and re-use, incentives for local authorities to promote waste prevention and intensify separate collection schemes and extended producer

responsibility schemes. Accordingly, action 1 of the EU CEAP states that the EC will "emphasise CE aspects in future product requirements under the Eco-design directive" (Scarlet, 2013). In these regards, one of the greatest technical challenges will be to include concepts as reparability, durability, upgradability and recyclability in the product policy debate. Secondarily, it will be necessary to develop assessment methods, using scientifically robust metrics, to measure the performance of each product (Talens Peiró *et al.*, 2019).

The regulative body may possibly play a key role in driving the widespread diffusion of circular practices, starting from the setting of specific targets to be followed by all concerned firms on the territory. The European Circular Economy Package indeed redefines the required recycling rates and the maximum landfill rate for municipal waste. Article 11 (2) of the amendment to Directive 2008/98/EC on waste (European Parliament and Council, 2008) states the following: *"In order to comply with the objectives of this Directive, and move to a European circular economy with a high level of resource efficiency, Member States shall take the necessary measures designed to achieve the following targets:*

a) *. . . by 2025, the preparing for re-use and the recycling of municipal waste shall be increased to a minimum of 55% by weight;*

b) *by 2030, the preparing for re-use and the recycling of municipal waste shall be increased to a minimum of 60% by weight;*

c) *by 2035, the preparing for re-use and the recycling of municipal waste shall be increased to a minimum of 65% by weight. "*

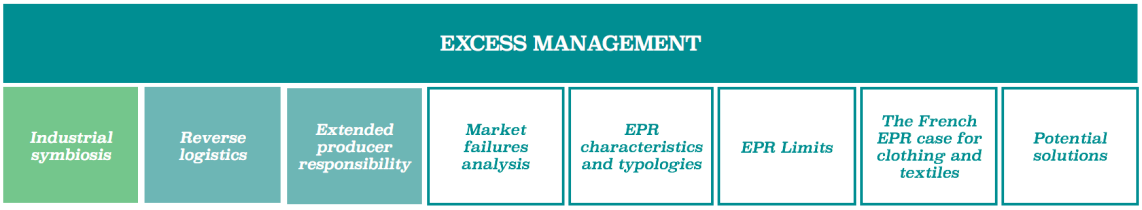
Then, in 2016, the EC proposed also new targets substituting the previous Waste Framework Directive by a Circular Economy Package, setting the recovery target for municipal waste to 70% and limiting the share of municipal waste to be landfilled to 10% by 2030 (European Parliament, 2017). Consistently, in order to meet the demands of the target rates set by the EU, the member states are required to optimize the national waste management in the direction of circular economy, being also provided with guidelines on how to quantitatively assess performances. (Sarc *et al.*, 2019)

Finally, relating to the fashion industry environment, the Waste Framework Directive has relevance to collection of used textiles, in terms of what it defines as waste, with strong implications for textile collectors. If the textiles they collect is defined as waste then this can mean that 1) the textiles are the property of the municipality or their assigned waste collector and the collector will need permission to collect 2) the collector may need to be registered as a waste collector 3) the collector may need to register the quantities of textiles they collect in a national waste register 4) the collector will need to have a filled out 'green list' waste shipment document, if they ship unsorted textiles across borders internally within the EU or EEA countries. Whereas, for what regards

the preparation for reuse, textiles that have been sorted into fractions to be sold for reuse are generally no longer considered as waste (Watson et al., 2018).

In future, excesses terminology and legislation will become an ever-more important feature in the facilitation of value circulation within superior waste hierarchy levels, while contrasting the flow into low value polluting end-of-life alternatives and thus also achieving the European targets set. Energy recovery is in fact actually much less effective than the theorized outcomes, causing extremely worse environmental impacts. As Sakai pointed out, urban communities often consider incineration facilities as sources of pollution and oppose local placement of new plants. As a result, new incineration plants are often located in less populated areas. Because demand for heat in such areas is limited, a large amount of heat generated these incinerators is not efficiently used (Sakai, 1996). Furthermore, incineration impedes the reuse and recycling of many valuable solid wastes that can be substituted for raw materials. (Geng, Tsuyoshi and Chen, 2010)

Thus, finding alternatives for diverting textiles from landfill and incineration is not only necessary to achieve the targets, but also to increase the materials efficiency, which is a vital element for promoting circular economy (Bukhari, Carrasco-Gallego and Ponce-Cueto, 2018).



First of all, the review of this sub-section shall start from analysing one of the most promising waste management systems from a general sector perspective, which is widely supported by the European Commission. The full application into the fashion industry may be intricate and not always beneficial, but important takeaways may be gathered and then integrated with other theories strength points.

1.3.1. *Industrial symbiosis*

An emblematic model of waste management is the one that establishes among a limited number of firms in a network of relatively strict partnerships, from which interesting insights may be gathered also for the optimisation of a prospective circular fashion industry ecosystem.

Precisely, industrial symbiosis (IS) is a system approach to a more sustainable and integrated industrial system (Chertow and Ehrenfeld, 2012), which identifies business opportunities that leverage underutilised resources (such as materials, energy, water, capacity, expertise, assets etc.) (Lombardi and Laybourn, 2012). IS involves organizations operating in different sectors of activity that engage in mutually beneficial transactions to reuse waste and by-products, finding innovative ways to source inputs and optimizing the value of the residues of their processes (Domenech *et al.*, 2019). Furthermore, according to the Ellen MacArthur Foundation, it constitutes a local partnership where, partners provide, share and reuse resources to create shared value. The purpose of industrial symbiosis is to create loops of technical or biological materials while minimizing the leakage and waste in the loops - demonstrating some key parts of a circular economy, at a local scale. (Ben *et al.*, 2010)

As a matter of fact, IS has now been officially recognized as a practical approach to promote CE and is also embedded in EU law through the final ratification of the EU CE package in July 2018. (Domenech *et al.*, 2019)

Some IS key success factors are worth a further deepening, due to their potential application in the process of facilitation of circular flows. One of the drivers for IS effectiveness and efficiency performances is the coordination of logistics (synchronization), which entails a mediation function aiming to match products with customer demand while lowering costs and minimizing uncertainties (Simatupang, Wright and Sridharan, 2002). Total supply chain costs are indeed lower in the integrated supply chain than in a supply chain managed by independent efforts (Tsay, Nahmias and Agrawal, 1999; Cachon, 2003). However, it is widely recognized that firms are not prone to integrate with each other, unless there is a central authority governing the entire system or strong social pressures (Albino, Fraccascia and Giannoccaro, 2016). Hence, as anticipated also regarding other issues earlier, policymakers and third-party organizations shall take an active part in designing the system in order to ease the individual firm-level initiatives and support supply chain collaboration. In particular, a fundamental objective would be to satisfy the win-win condition, which is required to guarantee a spontaneous emergence of symbiotic relationships (Albino, Fraccascia and Giannoccaro, 2016).

Another prominent IS feature to analyse is the significance of the diverse actors in the origin, progress and maintenance of such value-amplifying networks. As Mortensen and Kørnøv expound, businesses can play the role of an *anchor tenant*. Such companies, with their production streams, can get a number of by-products and need a number of resources. These can present a major source for symbiotic relations emergence. Knowledge and awareness of their potential could inspire other actors to initiate IS relations. (Mortensen and Kørnøv, 2002).

The study and improvement of the connective relationships among either old or especially among new partners is a widely relevant step in the thriving establishment of industrial symbiosis as of circular economy initiatives. In

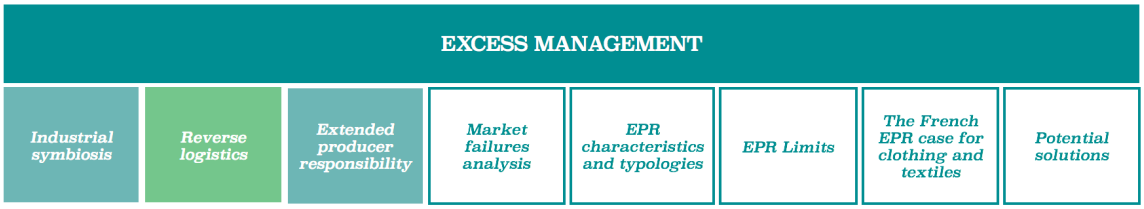
particular, as Prosman and Wæhrens state, an increased absorptive capacity enables the suppliers to align waste quality with production requirements. Managing waste quality is an important capability of industrial symbiosis, especially when firms want to go beyond the low-hanging fruits and increase the effectiveness of their industrial symbiosis activities (Prosman and Wæhrens, 2019).

In respect to this, it has to be noted that industrial symbiosis concepts embody some rebound effects and some limitations for the appliance to textile closed-loop systems. For instance, innovation in terms of clean technologies born from symbiotic relationships is rare since companies often focus on the reuse of waste, and not its prevention. Consequently, an important concern about IS is that it perpetuates waste streams instead of preventing them (Duflou *et al.*, 2012). The capacity to align waste quality with production requirements may actually even stimulate higher volumes of waste and thus completely oppose the waste hierarchy which should be desirably applied to the management of fashion excesses. Furthermore, industrial symbiosis pays off more the more diverse are the sectors of provenance of the network partners. This condition is actually counterproductive in the textile industry since, an open loop setting decreases in an unnecessary way the economic value of resources, while also permanently blocking their life cycle.

Furthermore, as Chertow points out, IS can manifest over different geographical distances from co-localization in industrial parks to larger regional developments (Chertow, 2000). Specifically, the scale of IS networks is dependent upon: 1) information flows with regards to types of waste/by-products produced by other companies/facilities; 2) understanding of opportunities derived from IS transactions and 3) know-how and resources for implementing the IS synergies. These elements are likely to emerge spontaneously between companies which are co-located, but less likely to happen when activities are not co-located unless there is a third party which acts as coordinator and centralizes information to identify opportunities. Additionally, another key factor influencing the geographical scale of networks is transaction costs, which include not only transport costs but also intermediation and negotiation costs (Domenech *et al.*, 2019). Intuitively, by increasing the geographical range, the number of potential partners is higher and total supply and demand of by-products (and excess utilities) also grows (Herczeg, Akkerman and Hauschild, 2018). However, increasing the distance inherently decreases the cost effectiveness of the by-product exchange and adds to the environmental impact due to the increased effort in transportation. Moreover, in case of perishable materials, a long distance is explicitly infeasible (Herczeg, Akkerman and Hauschild, 2018).

Hence, similar considerations may be consistently carried out while designing circular infrastructures, within which an optimal distance shall be identified. In these regards, it shall also be remarked that the impact of distance highly

depends on the resource type, which in case of clothing and textile fibres is quite durable, valuable and simple to be transported, thus admitting potentially long distances. For example, it is estimated that a textile recycling company can cover the costs of transporting the waste from the collector to the recycler within an area of 250 km; anything above this distance is currently financially not feasible (EURATEX, 2017). In future further solutions may be facilitated also through the support of IoT, since these technologies enable real-time control of flows or processes and thus a global scale of solutions as well.



At this point, aiming at reverse supply chain efficiency and full adoption of circular business models, the review shall continue with the analysis of trending models for the logistical optimisation of circular excess streams throughout the fashion industry.

1.3.2. *Reverse logistics*

The need to prolong the value chain in order to manage end-of-life steps of products to close the loop, intrinsically entails the need to optimise the reverse supply chain in order to provide the required materials qualities. Perhaps the most daunting obstacle in the establishment of a closed-loop fashion system, according to the Ellen MacArthur Foundation, is indeed the complexity of managing the circular value chain, which involves managing the return, recovery and remarketing of varying product models fed into the circular cycle at varying times and in varying conditions – this makes *predictability* a key challenge. The insufficiently analysed key building block of reverse logistics includes requirements such as asset tracking, optimized product and material flows and waste handling regulations; since preserving the residual value of return products is a challenge that is answered only by highly optimized logistics (Circular Economy 100, 2016).

Hence, based on the American Reverse Logistics Executive Council, reverse logistics is defined as "The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in- process inventory, finished

goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal" (Rogers and Tibben-Lembke, 1998). The related structure of flows is shown in figure 26.

According to Guide and Wassenhove (2003), product acquisition is the first step and is critical process for establishing the profitable RL, also because product returns are uncertain in terms of time, quantity and quality (Guide and Wassenhove, 2003). Further on, Zikopoulos and Tagaras (2008) found that sorting before disassembly and remanufacturing depends on the transportation, disposal and disassembly cost, and quality of returned product (Zikopoulos and Tagaras, 2008). Finally for the disposition, Krikke et al. (2003), and Tibben-Lembke and Rogers (2002) identified the following alternatives: reuse, product upgrade, material recovery, and waste management (Tibben-Lembke and Rogers, 2002; Krikke, Bloemhof-Ruwaard and Van Wassenhove, 2003), thus aligning with the waste hierarchy.

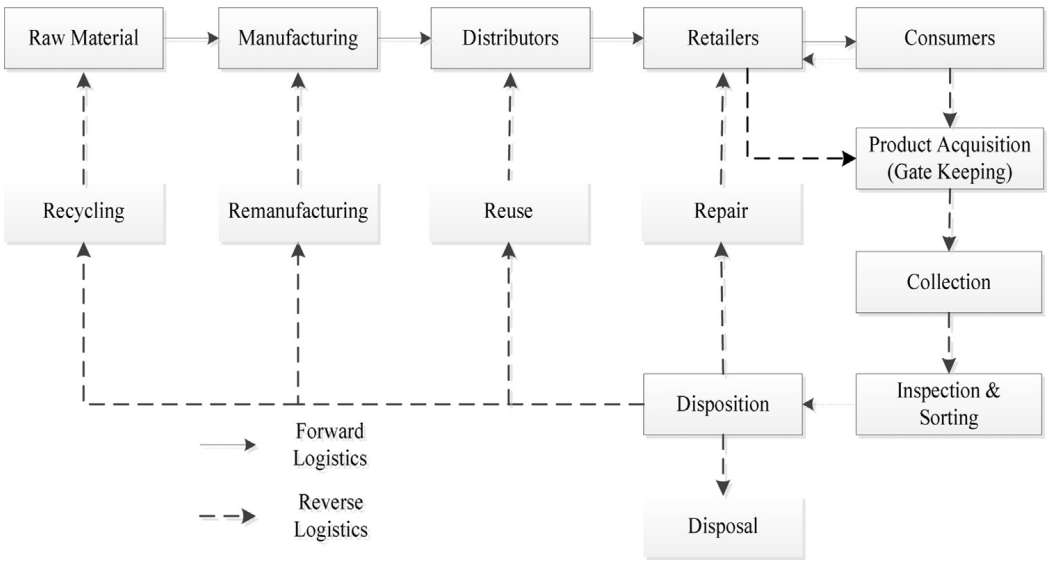


Figure. 26 - Basic flow of forward and RL process (Agrawal, Singh and Murtaza, 2015)

Moreover, as enabling requirement of a Closed Loop Supply Chain, reverse logistics follow and integrate all the circularity development steps, from a process management perspective to a comprehensive business model perspective, following the Reverse Logistics Maturity Model presented by the Ellen MacArthur Foundation (Circular Economy 100, 2016). Thence, starting from undefined, untraced, standalone RL activities all further steps are described till the optimization and monitoring of an integrated cross-functional process in line with business strategic goals.

However, RL is not a symmetric representation of forward supply chain (Fleischmann *et al.*, 1997; Srivastava, 2008). Hence, most industries still

struggle to employ RL strategies, also as a result of a lack of interest of their supply chain (SC) partners (Bernon *et al.*, 2013). Some firms consider RL an underestimated part of the SC for a plurality of motives, such as its uncertain profitability, its lack of people technical skills, and its difficulties with SC partners (Abdulrahman, Gunasekaran and Subramanian, 2014).

Indeed, RL implementation and management is commonly dependent (Govindan and Bouzon, 2018):

- *on the support and participation of the key stakeholders;*
- *on the shared responsibility through the reverse SC to bring back EOL products;*
- *on the resources committed to RL operations.*

From the environmental sustainability and economic performance perspective, the challenges faced by the RL include, how to reach real-time information for various tasks and vehicles with the performances of reducing (i) RL cost, (ii) fuel consumption, (iii) CO2 emission, and (iv) waiting time (Ganzha *et al.*, 2016)

In addition to these, in the literature review presented by Govindan and Bouzon, the most pressing barriers originate within the boundaries of the company. Many authors (Abdulrahman et al., 2014; Aitken and Harrison, 2013; Kapetanopoulou and Tagaras, 2011; Skapa, 2011) have recognized personnel resources issues, such as lack of training and low level of technical knowledge. Beyond that the lack of initial capital is a constant hurdle for innovative models but in this case it seems to be linked with the low involvement of top management (Govindan and Bouzon, 2018). In fact, in internal complexities, due to less visibility in reverse logistics, normally firms do not pro-actively carry out their planning and decision-making by taking into account the reverse logistics imperatives, but reactively responses based on the actions of echelons at the downstream (Tibben-Lembke and Rogers, 2002). Moreover, in connection to internal complexities, manifold efforts and resources have to be dedicated to organisational change management. RL implementation requires adaptations in procedures, utilization of human resources, leadership priorities and values. Thus, organizational changes that menace the status quo, such as RL endeavours, naturally encounter resistance at the many organizational levels (Gill, 2003; Lozano, Ceulemans and Seatter, 2015).

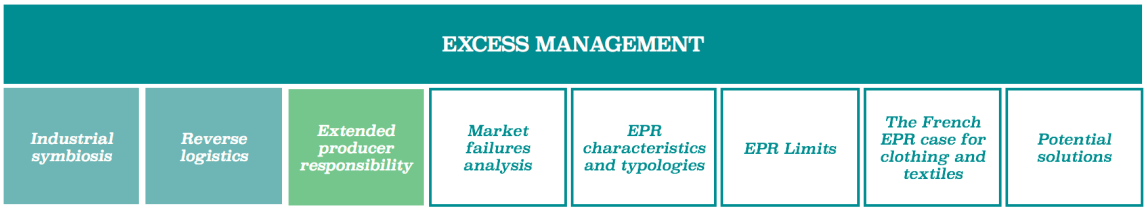
On the side of RL drivers, the most prominent ones originate from the surrounding environment. Pressures that emerge from stakeholders are considered one of the most relevant determinants influencing a company's environmental initiative, since “companies generally need to satisfy the demand of shareholders to prevent the loss of their capital investment” (Kim and Lee, 2012). Firms have also realized that a better understanding of product returns and efficient RL can provide a competitive advantage (JR and JP,

2009). Furthermore, among the actors pushing and pulling the shift, customers more dedicated to and aware of "going green" can compel enterprises to increase their recovery efforts. The coordination among stakeholders is the key to the success of the green supply chain management (Chen *et al.*, 2019).

In regards to green consumerism, product returns that are induced by trade-in rebates can be a significant source of revenue for a firm (Ray, Boyaci and Aras, 2005). For instance, offering trade-in rebates increases switching costs for current customers, provides incentives to new customers to switch from competing brands and increases customers' willingness to upgrade to new products/services (Sheu and Choi, 2019). Petersen and Kumar also pointed out that customer product return behavior is usually ignored or treated as a reverse logistics cost, but the associated benefits, including the potential profitability of future purchases and long-term customer lifetime value creation, are critically important (Petersen and Kumar, 2015).

Consistently, economic viability, attained third place, which shows that companies will not perform product return practices unless RL can improve economic efficiency (Govindan and Bouzon, 2018). Here, reverse logistics pricing strategy involves maximizing the amount of recycling while keeping the price of recycling constant or achieving a lower price, while expanding the scale of remanufacturing (Chen et al., 2019). From a holistic perspective, it is better for stakeholders to make their pricing and manufacturing decisions jointly which would lead to a higher level of revenue and quantity of recycled product (Chen et al., 2019). Hence, public-private partnerships will particularly benefit both the economical and environmental outcomes in the establishment of closed loop supply chains. Furthermore, Sheu and Choi state that the design and implementation of a Trade In For Upgrade program should be oriented toward "syncretic value" and in these regards extended consumer responsibility (ECR) results critical. In particular, the enhancement of brand loyalty through firm-consumer collaboration is recommended to help consumers reduce the intangible/psychological costs of generating the syncretic value and bear the ECR (Sheu and Choi, 2019).

Hence, as already anticipated, coordination and cooperation of the whole fashion system will be crucial, in particular for the balanced redistribution of responsibilities to each player according to the implementation of the polluter-pays-principle.



The final crucial model may be considered a combinations of diverse regulative measures and will lay the strategic foundation for the development of the novel framework.

1.3.3. *Extended producer responsibility*

While environmental benefits may be marked for most closed-loop excess management initiatives, the implementation of circular supply chains may be challenging from an economic point of view. Thus, bottom-up initiatives at a supply chain level might need to be incentivized also through some form of top-down governmental support (Genovese *et al.*, 2017). As anticipated, the whole systemic shift will require a widespread diffusion of circular practices and infrastructures in order to function properly and efficiently, thus incentivising economically and strategically also the less concretely sustainability-oriented actors, that for now still represent a wide majority globally. In turn, this implies that policymakers shall play an active role in supporting the scaling up of infrastructures and the incentives towards all supply chain players. These may take the form of either subsidies or environmental taxes according to the Polluter-Pays-Principle, in order to regulate the market and boost its expansion. Specifically, PPP is defined in the OECD recommendations as the allocation "of costs of pollution prevention and control measures to encourage rational use of scarce environmental resources and to avoid distortions in international trade and investment." Thus the polluter should bear the expense of carrying out the measures "decided by public authorities to ensure that the environment is in an acceptable state" (European Commission, 2012).

Still, there are no single economic measures which will solve the current state problems, thus policymakers shall develop an integrated and coherent regulative framework, which still is simple to understand and to apply following all the steps of a product life cycle. Consistently, along with other key economic instruments, the model of Extended Producer Responsibility may encourage a change in behaviour of all actors involved in the product value chain: product-makers, retailers, consumers-citizens, local authorities, public and private waste management operators, recyclers and social economy actors. (Oecd / European, 2014). According to the OECD definition, EPR is "an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle". The

Oecd (2001), inscribes EPR in the broader category of the polluter-pays principle (PPP), stating that it "extends" the concept of polluter to product themselves (OECD, 2001). Being the PPP so widely accepted, EPR's legitimization comes straightforward (Massarutto, 2014). Indeed, the provision of a system focused on extended producer liability appears to be the logical transposition of not only the polluter pays principle but also the principles underlying the waste hierarchy and is therefore considered a key tool in the promotion of the circular economy (Jacometti, 2019). The above-stated definition is however more problematic than it seems, since it is not obvious who the polluter actually is. Following the PPP approach, responsibility should be shared along the entire supply chain (Lenzen et al., 2007). In this line, emphasis should be driven away from producers, and regard instead the product itself, as the "Product Stewardship" movement suggests (Walls and Palmer, 2001).

Anyhow, the objective of both conceptions is to account for end-of-life management costs and activities by distributing benefits and charges among supply chain actors. Thus, the analysis will start from drivers and barriers for EPR schemes, then further considering consumer responsibilities as well.

The EPR principle has been initially proposed in the frame of management sciences and industrial ecology, as a way to improve resource efficiency (Massarutto, 2014). It rests on the assumption that patterns of waste generation result from the way the production and distribution are managed and organized; EPR implements the idea of "closed loops", promoting a re-design of value chains so as to encompass reverse logistics (Lindhqvist, 2000). Practically, since the reverse-logistics of the take-back system is characterized by economies of scale (Mayers, 2007). EPR may allow more efficient operations, simply because it is not constrained to the territorial base in which solid waste management services are usually organized (Massarutto, 2014).

In general, part of the rationale for the EPR approach is that placing responsibility for the end-of-life management of products on the manufacturer and/or importer will lead to improvements along the entire life cycle (Tekie et al., 2014). This is entailed throughout the proposition to drive and incentivise producers to: develop a sustainable production system and product design to make them durable and easier to repair and recycle; develop innovative techniques for recycling processes; and create new markets for recycled products (Oecd / European, 2014). Additionally, while pushing the environmental improvement within producers' boundaries, the scaling up of collection and sorting activities also enables progress in social sustainability thanks to the possibly high employment rate of people with difficulties in being hired.

So EPR schemes impact on the enhancement of both workers' wellness and also generally economic welfare, since it is a systemic way to realign the perceived individual firm level supply curve with the optimal supply curve from a social

point of view, thus contrasting the negative externality, minimizing overproduction and rising Pareto efficiency levels.

People have an asymmetric perception of what they spend, and are therefore more reluctant to accept an increase in the SWM fees than a correspondent increase in their shopping bill, since the price increase of market goods due to EPR would be quite small and difficult to appreciate. Of course, the same argument can also be reversed against EPR: the fact that it actually allows to hide the social cost of over-recycling may allow policymakers to set inefficient targets. At the same time, if the allocation of cost is fair enough, market shares will not be seriously affected and industry will be willing to participate, provided that the internalization of recycling costs will be absorbed without traumatic effects on equilibrium (Massarutto, 2014). If industry bears the cost of recycling, waste diverted from disposal entails a net saving for municipalities and SWM services. Municipalities would be thus more incentivized to collaborate with Producer Responsibility Organisations[4] (Xiang, Mei and Ye, 2014).

In the creation and subsistence of this virtuous cycle it is still fundamental to bear in mind that EPR aims at concretizing the waste hierarchy established with the European Waste Management Directive, taking care of minimizing possible rebound effects. Thus, as pointed in the Basel convention of United Nations in 2018, one of the elements which requires more attention is the use of EPR systems in improving the prevention of waste, both the waste arising from the products during their use and the products at their end-of-life, by encouraging at least, but preferably regulating, the sustainable design of these products, taking into account energy and material efficiency aspects, as well as consumer needs and behavioural aspects (UNEP, 2019). The reuse element gives by far the largest environmental gain per collected tonne compared to models based on recycling (Tekie et al., 2014). What emerges is indeed a fundamental agreement around the likelihood of a trade-off between recycling-oriented and innovation-oriented schemes. A combined tax-subsidy scheme, with subsidies directly paid to industrial R&D targeted to environment-friendly innovation would offer the best result. In order to foster Design for the Environment, incentives should be individualized: each firm should receive precise signals about the impact of its own products, that also function as rewards for DfE efforts. This can be achieved with an extensive program of individual take-back, that could be implemented for instance through leasing schemes and sufficiently high deposit-refunds. In alternative, each firm could be charged a personalized membership fee to collective PROs, taking into account the specific features of its product. If such a signal is not in place, the benefit of innovation will be shared by all, generating a classic free-riding situation. (Massarutto, 2014)

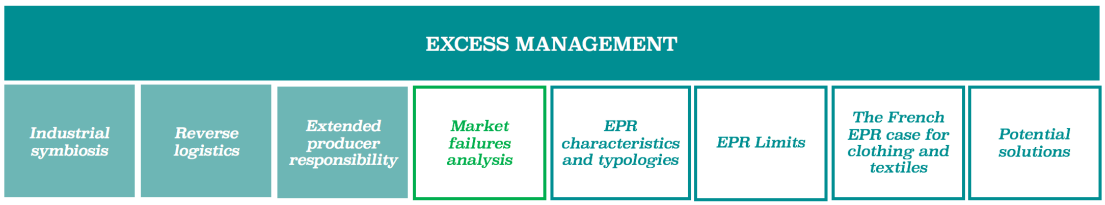
[4] Producers may abide by the law jointly, i.e., a producer joins a producer responsibility organization (PRO), and the PRO is responsible for fulfilling the producer's waste recovery responsibility

Hence, this reflects the abovementioned issues of influence of supply chain position, size or market power over the willingness and capability to invest in sustainability oriented innovations. In turn, aiming at the widespread implementation of the waste hierarchy, policymakers shall pursue an individualisation of charges and benefits, while integrating schemes of common end-of-life management in EPR with incentives towards autonomous closed-loop initiatives spurring disruptive solutions.

Furthermore, Porter and van der Linde (1995) also postulated a positive link between environmental regulation and competitiveness, provided that it is able to trigger an innovative response (Porter and Van Der Linde, 1995). Public policy shall so leverage on the factors that create competitive advantage in order to maximize the incentive (Massarutto, 2014). If companies will prize the possibility to consistently enhance both the environmental and economical long term sustainability, this shall automatically drive the widespread full adoption of circular economy models, pushing for systematic shift.

EPR shall therefore target mostly activities which are not likely to be functioning well on their own, as textile collection, sorting and recycling. Products with a high residual or positive value at the waste stage are generally voluntarily collected or taken back by the producer, while products with low residual value and high environmental impacts might be considered candidates for stronger governmental intervention. Voluntary systems are most commonly found in markets for durable commercial products and/or where products after becoming waste have value. Market forces will lead firms to take back products when it is profitable to do so. Voluntary systems may also be pursued by a producer seeking to prevent acquisition, refurbishment and resale of its own products by third parties (UNEP, 2019). Regarding the fashion industry, end-of-life management infrastructures at the current scale suffer from severe inefficiencies, however companies, in particular luxury brands, may be effectively willing to recover own products both aiming at positive brand image and marketing effects, but also to prevent illegitimate transactions in unknown end markets. Thus it will be necessary to balance the different measures in order to approach an optimal market equilibrium.

In particular, if markets were able to transmit price signals without frictions, EPR would be unnecessary: a waste collection charge incorporating externalities (e.g. a landfill tax, a tax on raw materials) would generate equivalent results without distortions (Kinnaman and Fullerton, 1999). Therefore, a theoretical justification of EPR should start from a recognition of market imperfections, and then discuss the capability of instruments of tackling with them (Walls, 2003). In other words, EPR is a typical second-best policy approach, whose essence lies in the attempt to correct market imperfections through the deliberate introduction of some distortions to its functioning (Walls, 2006).



Having defined how an Extended Producer Scheme is structured, the review shall now focus on thoroughly evaluating which are the market failures addressable by such a framework, in order then to dig into the single features.

1.3.3.1. *Market failures analysis*

As shown in figure x, as Massarutto (2014) displays, a socially optimum recycling rate corresponds therefore to the point where the marginal benefit[5] equals the marginal cost[6] (R*): beyond that level, an additional effort for increasing the recycling rate would imply higher costs than benefits. Governments, however, may choose $R_P > R^*$: this is equal to considering recycling as a "merit good", perhaps because some further values are believed to be associated with it, that go beyond individual utility and cannot be captured by monetary evaluation of benefits (Martinez-Alier, Munda and O'Neil, 1998). However, the market equilibrium is actually determined by costs and benefits perceived by operators. These may diverge from the social cost and benefit curves for many reasons (Walls, 2003; OECD, 2006) driving as overall result an inefficient equilibrium (r0 instead than r*), as shown in figure 27.

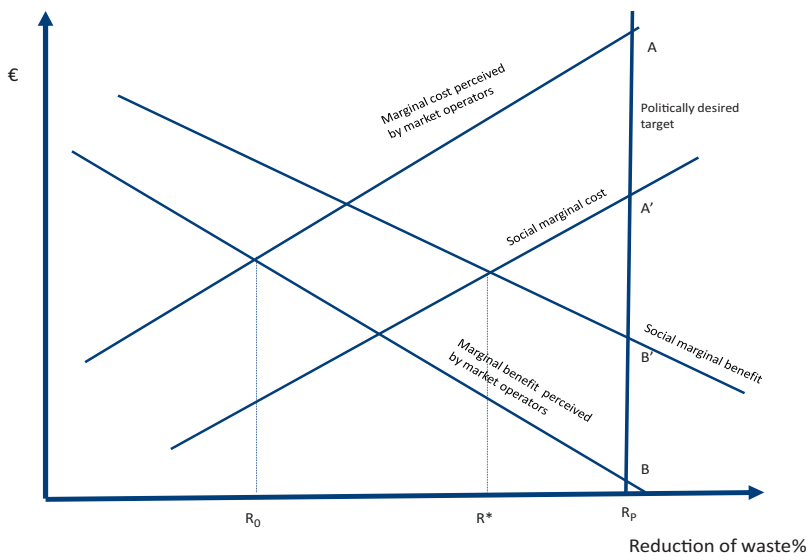


Figure. 27 - Socially optimal rate of waste reduction and market failures (Massarutto, 2014)

[5] Social benefits arise fundamentally from the market value of recycled materials and the saved costs. In addition, the "warm-glow" utility arises from the pleasure of behaving ethically. Generally, it is possible to suppose that the social benefit decreases at the margin with an increasing rate of recycling. (Massarutto, 2014)
[6] The marginal cost is supposed to have an increasing slope because of diminishing returns of these efforts. Preventing waste implies the sacrifice of utility associated to consumption, once the most obviously wasteful habits have been abandoned. (Massarutto, 2014)

Deepening the reasons for the divergence between the curves perceived by market operators and the ones which represent social benefits and costs, there are manifold externalities needed to be internalized (Massarutto, 2014):

- The *time horizon of policymakers* may not fully consider long-term implications of dissipative use of resources and thence adopt a discount rate that undervalues future benefits

- There is a huge issue regarding "*unfair competition" of illegal disposal*

- Interstate trade of materials creates opportunities for *"masked dumping",* facilitated by asymmetric regulations and looser enforcement in the "waste heavens"

- An efficient collection requires an interplay between operators (who have to provide convenient and accessible systems) and users (who are supposed to effectively participate). Transport and logistics have to be optimized. Facilities have to be located and sized accordingly, technological choices should be coherent etc. This arises a classic *collective action problem*, particularly in the early phases when the "reverse logistic" system is not developed

- *Actual costs might differ from efficient costs* because SWM operations are focused on unsorted waste collection and disposal and follow administrative boundaries, without efficiency concerns

- Quality of recycled materials is often difficult to assess ex-ante. As anticipated earlier, this arises a typical "*market for lemons*", namely a situation that takes place when better-than-average quality products are excluded from the market because nobody is willing to pay more than an average price, taking into account the risk of buying low quality

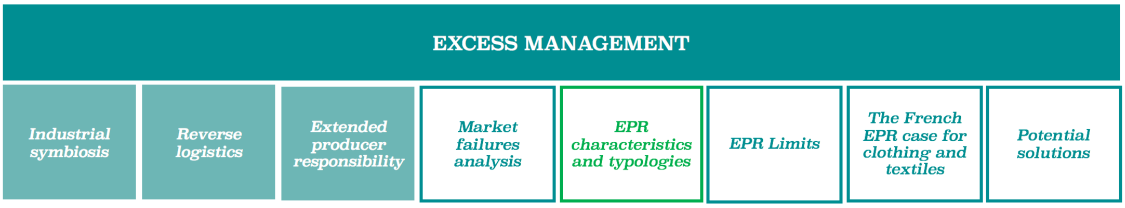
- *Transactions costs* may also arise from price instability and risk of unavailability of a market for sorted materials

- *Market power* also matters. For instance, manufacturers are incentivised to improve recyclability only if they can steadily benefit for the higher margin generated; yet recyclers may well appropriate the most part of it

- Behavioural studies reveal that the willingness of households to engage in separate collection is high, but requires to win the inertia of deep-seated habits and therefore implies a *social learning process* toward a recycling-oriented culture. The effect of innovation and social learning could be that of shifting the marginal cost to the right and the marginal benefit upwards, or lower the slope of both

The noticeable multiplicity of market failures arises the necessity to develop a more complex policy design. As mentioned above, when policy targets shift from media-specific pollution to product life-cycle optimization, however, no single instrument, not even an optimal tax that accounts for all externalities (what economists define as a "pigouvian tax"), can deliver optimal results (Massarutto, 2014). Using complementary instruments is indeed particularly important, when the policy has to address multiple market failures and transactions costs are relevant (Walls and Palmer, 2001; Lehman, 2012). Consistently, many have noted that EPR is not an instrument, but rather an over-arching policy principle, that could be enacted with many combinations of instruments (Walls, 2003).

Of course, there is concern about the market power acquired by PROs. Finding the right balance is difficult because it depends on the structure of each industry and possibly varies in time and space. Anyhow, EPR systems entail different patterns of possible cost allocation between taxpayers, SWM service users and consumers (Massarutto, 2014). Aiming to favour the individualisation of incentives according to the supply chain and market power structures of each industry, EPR schemes shall thus be designed with particular care for each differentiating feature.



The previous chapter unfolded the variety of market failures and the need for a more complex policy design. In these regards, the following chapter will present the main alternatives available when structuring such a regulative framework.

1.3.3.2. *EPR characteristics and typologies*

In accordance with the previous section, the OECD guidance on EPR entails four main principles relating to the many design and implementation features compared (Oecd / European, 2014):

1. ***Allocation of responsibilities among stakeholders:*** *the responsibility of producers may range from simple financial responsibility to full organisational responsibility.*

2. ***Costs coverage**: what types of costs are covered by EPR and in which proportions? To what extent does a producer's financial contribution truly reflect the end-of-life costs of its products?*

3. ***Fair competition**: How is economic competition organised within EPR schemes, in particular at the level of Producer Responsibility Organisations (PROs) and waste management operations?*

4. ***Transparency and control**: which are the reporting requirements for each actor? Who monitors the different aspects of an EPR scheme and how?*

Commencing with the allocation of stakeholder responsibilities, despite EPR being in theory an individual obligation, in practice producers often exert this responsibility collectively. In collective schemes, a Producer Responsibility Organisation (PRO) potentially exerts three main functions:

- *Financing the collection and treatment of the product at the end of its life (targeted waste stream) by collecting fees and redistributing the corresponding financial amounts;*
- *Managing the corresponding data;*
- *Organising and/or supervising these activities.*

Since 2004, two main evolutions of EPR have occurred:

- whereas the initial fees paid by producers represented only a partial contribution to solid waste management costs, the operational costs coverage by producers' fees has gradually increased, sometimes reaching 100%;
- whereas the PROs were initially created as entities whose role was merely to aggregate the producers' financial contribution, their role has been drifting towards more operational interventions and a broader scope of action (data management, organising operations, launching bids, communication campaigns, etc.).

Specifically, the legal status of PROs varies widely. PROs can be non-profit organizations (typically), government agencies (rarely), quasi-governmental non-profit organisations (occasionally) and for-profit firms (occasionally) (UNEP, 2019).

The producers' responsibility within an EPR system is always financial and may also be operational, following several possible combinations (UNEP, 2019):

(a) '*Simple' financial responsibility*: producers have no other obligation but to finance the existing waste management channels, individually or through a PRO, eventually including management of fees to be collected from consumers;

(b) *Financial responsibility through contracts with municipalities*: producers establish contracts with municipalities to manage waste (e.g. packaging). The producers' motivation to improve waste management depends on the type of contract and on the dialogue with municipalities;

(c) *Financial responsibility and partial operational responsibility*: some activities are kept under the responsibility of municipalities (e.g. collection, whether implemented directly by public waste collection operators or contracted to private companies), backed financially by producers, whereas some other activities (e.g. sorting, recovered materials reselling) are under the responsibility of producers;

(d) *Financial responsibility and full operational responsibility*: The producers subcontract activities to professional waste collection and disposal operators, or even own part of the collection and disposal infrastructure.

Evidence of inefficiency and cost increment has led to an increasing number of EPRs that involve multiple PROs, even though the conditions in which a monopoly PRO is more efficient than multiple PROs have not been determined. (Bukhari, Carrasco-Gallego and Ponce-Cueto, 2018)

Hence, in general, when run collectively, mandatory EPR has the potential for capturing large quantities of used textiles cost effectively. Individual voluntary EPR schemes, however, include stronger incentives for so-called upstream effects i.e. improvements in design to benefit reuse or allow effective recycling. Collective EPR schemes can encourage these effects but only if designed carefully, since normally they do not offer enough incentives for promoting waste prevention and green product design (Plambeck and Wang, 2009; Favot, 2014; Esenduran and Kemahlioglu-Ziya, 2015). On the other hand, it is recognised that mandatory or widely adopted voluntary collective EPR systems can collect much larger volumes than in-store collection and resell of used own brand models. (Tekie et al., 2014)

Anyhow, the OECD analysis also states the following general conclusions (Oecd / European, 2014):

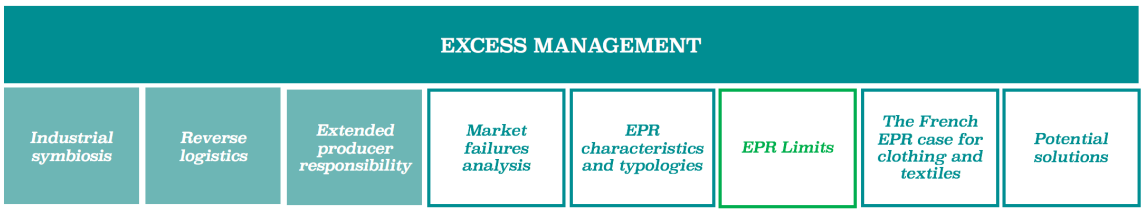
- *The best performing schemes are not, in most cases, the most expensive.*

- *Fees paid by the producers vary greatly for all product categories. These differences reflect either a difference in scope and cost coverage, or in the actual net costs for collection and treatment of waste (or both).*

- *No single EPR model emerges as the best performing and the most cost-effective.*

Analysing the case of fashion, mandatory and voluntary collective EPR systems seem to have a significant impact on collection of used textiles, but a more limited effect on the pre-consumer stages of the textile life cycle. While, widespread use of alternative business models, such as leasing and resell of own brand, have a clear upstream effect, but perhaps more minor impacts on overall collection, reuse and recycling (WRAP, 2018).

In conclusion, it is evident that it will be necessary to define the system according to the optimal exploitation of each possible feature, relating to the potential role in maximizing either infrastructure efficiency or effective innovation and improvement, in order to contrast the manifold challenges characterising the application of EPR schemes to specific industrial sectors.



Given the intricacy encountered when designing an EPR scheme, there will accordingly arise also a wide variety of issues and limitations in the related application or effectiveness.

1.3.3.3. *EPR Limits*

Summing up, the impact of EPR on green design and product innovation has been much lower than expected (Walls, 2006). Even considering that concepts such as "recyclability" are slippery and very difficult to measure, especially on an aggregate base, most of the applied research so far provides scant evidence of a decisive shift in this direction. While concerning the facilitating recycling, success is indubitable. Additionally, the advent of EPR is always correlated with booming increases of separate collection and recycling (Massarutto, 2014). Still, in the design phase of the regulation, policy makers shall regard the persistence of the following possible systematic failures (Oecd / European, 2014):

- **Imprecise responsibilities and insufficient formal dialogue among stakeholders**

  In this case it is suggested: the definition and objectives of EPR should be precisely clarified and the responsibilities and roles of each actor should be explicit along the whole product life cycle

- **Producers' fees seldom reflect the true management costs (coverage issues)**

  The extent to which net operational costs are assumed by PROs (and therefore covered by producers' fees) is highly variable and depends notably on the share of organisational and financial responsibilities of the various stakeholders, as well as on the national framework for EPR. Anyhow, wrong costs allocation fundamentally undermines the effectiveness of such schemes. For instance, although sound waste management and recycling have generally improved, notably through the implementation of EPR, there is no clear evidence of a strong positive impact of EPR on the eco- design of the products:

  - Few or no targets or indicators regarding eco-design have been developed.

  - The development of collective schemes, which mutualise responsibilities of many different individual producers, involve a risk of 'averaging' the costs among producers, thereby de-incentivising individual efforts for eco-design.

  Among suggested guiding principles, there seems to be a consensus on the fact that EPR systems should cover the collection, sorting and treatment costs of separately collected waste management minus the revenues from recovered material sales (thus the full net cost). Additionally, the fees paid by a producer to a collective scheme should reflect the true end-of-life management costs of its specific products.

- **Fair competition should be ensured**

  Centralised systems are frequent but there is no evidence that a centralised organisation is preferable to the introduction of competition among PROs or vice-versa.

  Suggested guiding principles: Notwithstanding the way competition takes place, a clear and stable framework is necessary to ensure fair competition, with sufficient surveillance and equal rules for all, supported by enforcement measures (including sanctions).

- **Insufficient transparency and need for surveillance**

  Optimal transparency can be reached through different measures:

  - Ensure data availability, especially when several PROs are in competition;
  - Ensure materials' traceability;
  - Develop relevant indicators and ensure comparability;
  - Precisely define data collection and reporting methods, notably: recycling rates and operational costs.

  Additional control activities are necessary as well: Identification of free riders and enforcement, Surveillance of treatment operations, Surveillance of PROs. Suggested guiding principles: transparency is required on the performances and costs of EPR schemes, thus key definitions and reporting modalities should be harmonised at the European level. Member states and obliged industry should be co-responsible for the monitoring and surveillance of EPR schemes and should ensure that adequate means for the enforcement are in place

Beyond these scheme design failures, there are other possible implementation failures regarding the incorrect exploitation of EPR features:

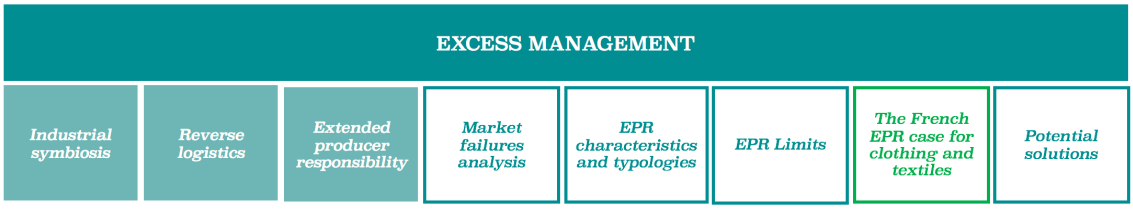
- Concerns exist about **collusion among producers** and about the **potential abuse of vertical agreements between PROs and companies involved in downstream operations**. Services such as waste collection, pre-treatment, as well as recovery and final disposal, should be procured by transparent, non-discriminatory and competitive tenders (UNEP, 2019). This also links to the creation of a possible drive towards illegal collection initiatives, then partnering up with incorrect PROs.

- **Online sales are creating new free-riding opportunities as consumers are able to buy more easily from sellers in other countries**. These sellers often have no physical, legal entity in the country where the consumer resides, and are not registered with national or local EPR schemes. The consequence is that they avoid producer and retailer/distributor obligations and costs, thereby undermining EPR systems. This leads to three main problems (Hilton et al., 2019):

  - Free-riding that consists in not undertaking physical 'take-back' obligations leads to lower collection rates for end of life products

- Free-riding: not paying EPR fees challenges the financing of waste management activities
- Free-riding by under-estimating the number of products placed on the market results in a potential over-estimation of national recycling rates

Eventually, the management of all these limits will need to be tailored to the specific industrial sector in consideration, studying the optimal exploitation of the digital and physical technologies present.



Beyond the manifold limits of an EPR scheme, the review will now deepen an already functioning real case, in order to further define its efficacy points and weaknesses in achieving the aspired target results.

1.3.3.4. *The French EPR case for clothing and textiles*

In order to understand the current state limits and potential improvements, the review shall now focus on the analysis of a concrete application of EPR for the fashion industry.

The best indicator of the collection performance of a country is perhaps the quantity of collected used textiles expressed as a share of new textiles put on the market, rather than kg/capita. France is a good example of how a country with a previously very low collection rate can increase collection significantly via ambitious policy. Prior to Extended Producer Responsibility Regulations being adopted in France, collection rates were low. They have doubled from 18% to 36% between 2010 and 2016 (EcoTLC, 2010, 2016) as a direct result of the activities of EcoTLC, the organisation who carries out the responsibilities of producers under the regulations, and its associated partners; charities, private collectors and municipalities. Activities have included increasing density of collection points, economic support of textile sorters to increase prices for

original, R&D in recycling initiatives and communication campaigns with citizens. (Watson et al., 2018)

Technically, the tariffs for members' contributions are calculated every year, depending on the previous year's expenses (Bukhari, Carrasco-Gallego and Ponce-Cueto, 2018), relating to different product categories. Applicable products must:

- *Be intended for the French national market and/or French overseas territories: Guadeloupe, Martinique, Guyana, Reunion Island, Mayotte, St Pierre and Miquelon, Saint Martin*
- *Be intended for consumers or household consumption and*
- *Be new*

Then the funds collected are used towards supporting (EcoTLC, 2020):

- All sorting organisations that respects Eco TLC requirements;
- R&D projects that are selected by a Scientific Committee to find news outlet and solutions to recycle used Clothing, Home textiles and Footwear;
- Communication campaigns organised by local authorities to motivate end-used to change consumers waste sorting habits.

Furthermore, the PRO incentivises textiles producers by reducing the annual tariff when they use recycled fibres made from pre- consumer or post-consumer textiles, linen and shoes. Producers can benefit from the 'Eco-Module (1) Tariff', which represents a 50% discount over the normal tariff if their products have a proven minimum composition of 15% of post-consumer recycled fibres or materials (see tariff in figure 28). They can also benefit from the 'Eco-Module (2) Tariff', a 25% discount over the normal tariff if their products have a proven minimum composition of 30% of pre-consumer recycled fibres. To be eligible for an Eco-Module tariff, the PRO examines supporting documents, provided by the main producer, that prove the type of recycled components, the origin of used material, and their proportion in the composition of the new products. Member companies whose revenue is under €750,000 or sell less than 5000 items in year (n – 1) are entitled to contribute a fixed tariff of €36 plus VAT (EcoTLC, 2016).

In respect to awareness enhancement activities, the PRO has also launched an interactive website and mobile application to educate consumers on how to recycle their clothing properly and show them the nearest collection points around them.

Product	Size Category	Examples	Tariff (€)		
			Regular	Eco-module(1)	Eco-module(2)
Garments & linen	Very Small Item	Socks, kids' underwear	0,00132	0,00066	0,00099
	Small Item	Shirts, leggings, lingerie	0,00528	0,00264	0,00396
	Average Item	Pijamas, nightdress	0,00791	0,00395	0,00593
	Large Item	Adult's jacket, coat	0,0528	0,0264	0,0369
Footwear	Small Item	Slippers, mules	0,00528	0,00264	0,00396
	Average Item	Shoes, boots	0,00791	0,00395	0,00593

Figure. 28 - Tariffs for 2016 members' contribution (EcoTLC, 2016)

Results demonstrate the potential of such EPR schemes for the end-of-life management of textiles but also show improvement margins in various dimensions. As shown in figure 29, in 2015, the 'reuse' stream was about 65% of the overall collected textiles. However, most textiles in this stream exported to the second-hand market in Africa and few were sold in France. Also, around 35% of the materials were down-cycled (9% to produce rags and 24% to produce insulation materials) and about 6% were either landfilled or incinerated. (Bukhari, Carrasco-Gallego and Ponce-Cueto, 2018)

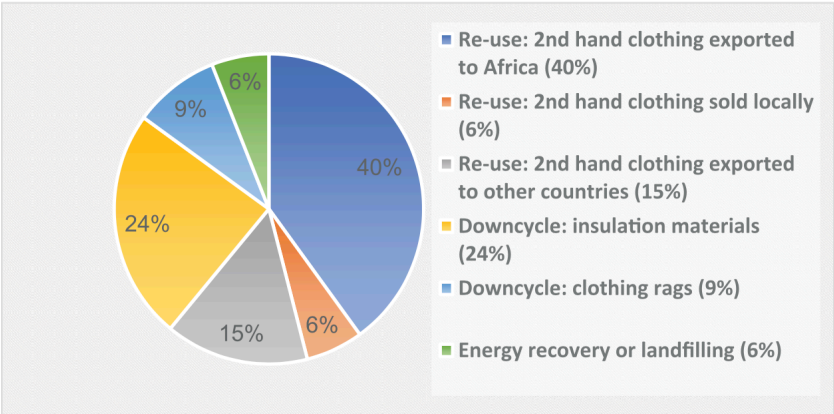


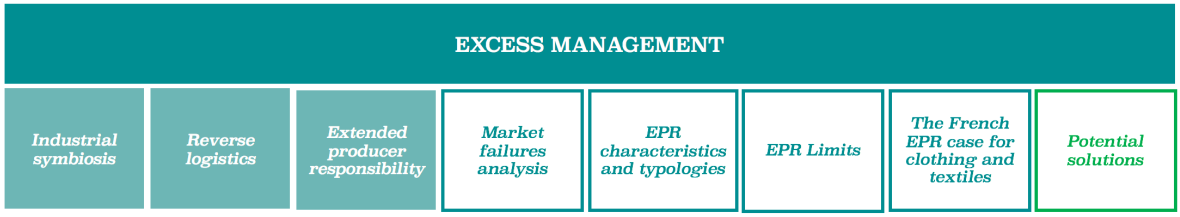
Figure. 29 - Redistribution of post-consumer textiles and clothing in France (EcoTLC, 2016)

Regarding present systematic weaknesses, despite a 50% discount on the tariff that has been offered for these items, the discount remains too low to cover the administrative costs linked to the declaration per unit and the certification of the origin of the recycled material used (EcoTLC, 2016). Thus, fashion retailers find it infeasible to report their clothing made out of post-consumer textiles. They also find it easier and more feasible to report and use pre-consumer materials obtained from textiles production waste (EcoTLC, 2016). In addition, the PRO does not give producers incentives such as eco-module tariff when they ecologically design and source other materials. (Bukhari, Carrasco-Gallego and Ponce-Cueto, 2018)

Finally, the French PRO doesn't manage and optimise the reverse distribution network for collection routes and sorting facilities' locations, which implies that

collected textiles might not be transported to the closest recycling facility even though smaller loops (collection, re-use, and recycle) are generally more profitable, eco-friendly and resource efficient, due to less transportation distance and other transaction costs (Stahel, 2013).

Hence, the French example displays weak performance points but also provides a solid basis from which confidence can be retrieved in order to study future developments and potentially satisfy all improvement margin challenges.



Given the concrete example of EPR application to the apparel industry, potential innovations for the resolution of the stumbling blocks encountered shall be investigated and developed.

1.3.3.5. *Potential solutions*

In conclusion, it has to be noted that there already exist valuable conceptions to solve systematic failures and implementation hurdles.

First of all, as already mentioned above, the fee should be established per product, this way the fee can be linked directly to the cost of collection and disposal of the product when it becomes waste, which simplifies communication to the market and households. The definition of categories and subcategories per product should be used to allow for cost differentiation, for example in the case of packaging, different categories and subcategories might be considered by material and size. Fees should be transparent, and might be visible or non-visible on the product. The fee is an important tool to create public awareness, as they relate to the cost of collection and disposal of the product when it becomes waste. Customers could use it as a way to choose sustainable products. Competition should be based on the product market, as well as on the collection and disposal markets, and not on the fee (UNEP, 2019).

Further on, it is useful to link EPR registration with other regulatory measures. For example, when companies are applying for a Value Added Tax registration, they could be made aware of the need to also register for EPR. Similarly, it shall be considered to make producers aware of their Extended Producer Responsibility obligations through the documentation and awareness

raising activities linked to meeting technical and safety standards (e.g. Conformité Européene markings in the EU and the equivalents elsewhere). In these regards, an additional but more complex step would be to make EPR registration a condition of obtaining a CE mark for those putting products onto the EU market. (Hilton *et al.*, 2019)

The exploration of technological solutions (block-chain and smart contracts for example) to automate EPR processes and payments was also proposed. Goods could be "linked" with their digital counterpart through unique identifier codes registering any EPR payment. Cross boundary movements between nations could be reflected in the system and payments either transferred from one country to another or refunded to the exporting entity. Furthermore, the implementation of smart contracts with partially or fully self-executing clauses is another promising technology that could be explored. Respective contractual rights and obligations could be automatically activated by an independent system when a triggering event occurs. In the context of EPR and online sales, the triggering event could be determined as the "order" combined with the "delivery address" which in combination could respectively determine the time when the payment is due and the entity the payment has to be remitted to. As a further step, multi-seller online platforms that operate a fulfilment house in a country could be defined as the producer of the products that they list from non-registered companies, even where they are not technically the seller. Distance sellers often have contracts with courier organisations such as FedEx, USP, and DHL. It has therefore been suggested that these organisations could take on aggregate producer responsibilities, as the de-facto importer, where the distance seller is not registered in the territory where the parcel is being delivered. This would almost certainly make the courier companies take the EPR issue into account when negotiating contracts with large online sellers overseas, as part of a wider due diligence process. Additionally, vertical integration, between couriers (e.g. DHL) and PROs (e.g. ERP), potentially provides an added incentive to be proactive in reaching out to distance sellers, as there is potential commercial benefit in providing both courier and environmental compliance services bundled together across the EU and beyond. However, there is no evidence that these integrated services actually provide additional quality and transparency, and that they are a guarantee of compliance. (Hilton et al., 2019)

Furthermore, block chain technologies also intrinsically support the monitoring and tracing of the textiles flow, while also driving the accomplishment of the objectives of subsidies enabling recycling organisations to: improve their performance; increase their sorting capacity; and improve the sorting and recycling performance. (Bukhari, Carrasco-Gallego and Ponce-Cueto, 2018) Finally, consumer-awareness is a key for raising consumer interest in buying second-hand clothing and disposing their used clothing properly. (Bukhari, Carrasco-Gallego and Ponce-Cueto, 2018) Thus, EPR schemes shall involve also consciousness and knowledge raising activities among end users.

Section 2

ON-FIELD INDUSTRIAL OUTLOOK

In order to complement the state of art of circular economy and waste management theories for the fashion industry, the review shall now pursue the analysis of concrete business insights, gained through a diversified interview-based research, comprising stakeholders from all edges of the value chain. As anticipated, one of the current state crucial problems is the inaccuracy and ineffectiveness of incentives for the urge of making supply chain actors transition from occasional and isolated business models innovation towards the full adoption of circular and sustainable practices, which in this section are addressed as synonyms. It becomes therefore fundamental to assess the concrete reality behind articles and reports, in order to discern which proposed panaceas have real potential to stick to the business fabric.

In these regards, interviews were carried out along the whole process of conception of the model. When possible (5 cases over 16 interviews) it was preferable to visit the site and have a conversation in physical presence, otherwise an online video conference would be chosen. Aiming at the neutrality of responses, in 4 cases the interviewees were more than one, representing different functional units of the firms assessed.

In particular, the principle questionnaire (reported in detail in **Annex I**) includes questions aimed at investigating the diverse perspectives and requirements of each supply chain stage, the level of sustainable innovation or strategic orientation in the current state of the fashion industry, the level of collaboration within supplier relationships, the feasibility of digital and recycling technologies in the textile and clothing environment and the viability of extended producer responsibility schemes. The qualitative and partly quantitative information set gathered, shall thus serve for the proper design, calibration and implementation of the novel framework proposed.

2.1 State of the industry and future orientation

It is relevant to notice how all interviewees confirm and demonstrate a strong drive towards sustainability within their investments, R&D efforts and organisational choices. As neutral cross-industry stakeholder, Circle Economy elucidates: "we can observe from the past years that more and more companies are starting to focus either on sustainability or on circularity and we can see that mainly through target-setting, both internal targets but also brand/industry alliances" (*Interviewee 14*). Whereby the diagnosis aligns with the considerations developed in the Pulse of Fashion Report, where it is explained how the Pulse curve rises along with increasing Pulse Score levels, once companies set strategies and targets and lay the foundation to increase their environmental and social performance (Lehmann *et al.*, 2018). Thus it is likely possible to position the current state of the fashion industry at 'Phase One', right beyond the initial application of uncoordinated actions with low improvements in environmental and social performances.

In 'Phase One' the Pulse Curve effectively starts to rise more than linearly in line with a boost in the Pulse Score (Lehmann *et al.*, 2018). Currently, "piloting processes through minor projects are increasing but there is still a long way to go on how to change the whole business, how it works, how the supply chain works, how the communication works and also how to create the right incentives for the whole system to change" (*Int. 14*). Hence the next years will be decisive for either the success or the ineffectiveness of the transition towards a value-maximising circular economy. According to Lenzing: "We will see a lot of shift in business models, shift towards environmental-friendly and sustainable materials, while also durability will probably get much more important. So it might be that even though companies believe they sell less, the quality of clothing and fabrics will probably increase" (*Int. 1*). In these regards, Brugnoli points out the diverse paths to possibly undertake the sustainable development of a fabric manufacturer. On one side, it is fundamental to lead the company philosophy towards the aim of producing articles that may last during time satisfying their primary function. Consistently, all the processes shall minimize use of energy, water and raw materials, comprise premium inputs and methods patents, exploit renewable sources, be constantly modernized or optimised, reuse resources and packaging, minimize handling and transportation. All together this support the achievement of several certifications, such as: 'OEKO-TEX', 'Tessile Salute', 'GRS', 'BCI' and so on so forth. On the other side, referring to the product, there is the choice for eco-friendly fibres put on the market only in case of satisfactory performances in quality and cost, expected and required, according to their principle of "Sustainability without compromises". This aligns with Porter's objection of inconsistence of the conflict between environmental sustainability and economic competitiveness, in the context of incumbents. Whilst, for what

regards start-ups, according to Brugnoli it is not always possible to reach this equilibrium because of missing confirmations on final product's quality or instability of the fabric itself. In these regards, Brugnoli points out the diverse paths to possibly undertake the sustainable development of a fabric manufacturer. On one side, it is fundamental to lead the company philosophy towards the aim of producing articles that may last during time satisfying their primary function. Consistently, all the processes shall minimize use of energy, water and raw materials, comprise premium inputs and methods patents, exploit renewable sources, be constantly modernized or optimised, reuse resources and packaging, minimize handling and transportation. All together this support the achievement of several certifications, such as: 'OEKO-TEX', 'Tessile Salute', 'GRS', 'BCI' and so on so forth. On the other side, referring to the product, there is the choice for eco-friendly fibres put on the market only in case of satisfactory performances in quality and cost, expected and required, according to their principle of "Sustainability without compromises". This aligns with Porter's objection of inconsistence of the conflict between environmental sustainability and economic competitiveness, in the context of incumbents. Whilst, for what regards start-ups, according to Brugnoli it is not always possible to reach this equilibrium because of missing confirmations on final product's quality or instability of the fabric itself (*Int.3*).

Generally, the trend in improvement of material mix choice and sourcing seems to represent the main strategic objective of the majority of firms. In December 2019, VF launched new Science Based Targets in order to define the strategic roadmap for the reduction of emissions, detecting a percentage of around 40% of the overall emissions coming from materials choice. They describe their fibres strategy as "Material Vision properly because some technologies are still under development and by 2030 this strategy will lead the company to source materials defined either 100% renewable, 100% regenerative or 100% recycled with a preference towards closed-loop" (*Int. 6*).

Consistently, Candiani states: "We are seeing the demand for sustainable materials growing, specifically organic increased exponentially in the last year till the point that we had safeguarded our supply for the next year and we're already short now" (*Int. 5*). Lenzing quantified this tendency with a perceived increase in demand for alternative recycled materials of around 15-20% within the last 3 years (*Int. 1*). Among the other chemically recycled fibre producers, Renewcell adds: "The fashion and textile market is growing without us needing to do anything. Also the interest in sustainable materials is only growing as well. Just qualitatively the interest we get is massive" (*Int. 13*). Similarly, Chemical Recycler X explains how interest for circularity grew indeed exponentially, i.e. around 60% in the last 2 years (*Int. 12*). This demand for closed-loop systems, may be seen in the retail stage as well, since according to Luxury Brand X: "There is a huge number of requests and willingness to pay much more for garments from past collections, even vintage ones"; thus demonstrating the frontline role of the luxury segment in rendering these

business models feasible, effective and finally more profitable than the business-as-usual scenario (*Int.8*).

The full circular economy adoption, both upstream and downstream, shall entail a true integrity in objectives in order to satisfy all potential benefits claimed. MUD Jeans gives thus weight to the fact that they deeply believe that circular and sustainable has to go together, because "you cannot be a circular company and then use toxic materials even if you recycle them" (*Int. 7*). In turn, Candiani states: "Well money is always a barrier but at least for us sustainability and circularity are almost synonymous, so all R&D efforts are put towards that" (*Int. 5*).

2.2 *Circular and sustainable opportunities*

Undoubtedly, the opportunities available to true sustainability and circularity champions are manifold and of diverse nature.

According to MUD Jeans, "Being a purpose-driven company it is easier to find motivated, qualified, intelligent and productive people". The CEO devotes indeed great value to transparency and puts forward their strategy for the systemic development of the whole fashion industry, by being the example other big firms shall desire to follow. "Being transparent also attracts a lot of attention to us and gives a lot of free publicity, we have a very large group of followers and people that talk about us on social media, thus this comprises a lot of influence that pushes our brand automatically. Given the great effectiveness of this kind of marketing, we're now also driving an ambassador program where we ask our customers to post pictures and leave feedback with our products" (*Int. 7*). Similarly, also for the case of Orange Fiber, advertising investments have been negligible since foundation: "Today Orange Fiber is not just an innovative material, even before it is a brand, a storytelling, which is recognized and appreciated worldwide. To date, there is still a multitude of articles being published referring to the collection that we launched two years ago in collaboration with Ferragamo. Not even one of these has been purchased." (*Int. 2*).

Many alike examples actually show a surprising effectiveness and influence on stakeholders' behaviour, supporting the minimization of operational costs and the maximisation of earnings. This general advantage will then diversify in strength according to integrity of the firms' objectives and accuracy of market and products strategy for each fraction of customers. About this, Circle Economy further explains: "On the main opportunities, I think it will depend a

lot on the market segment that you are tackling. A rental model in a very low price segment might be much more difficult to really implement cost- and quality-wise. Something we always support is taking a step back and really looking at the waste hierarchy and always reduce consumption first. If you're reducing consumption you also reduce production, then you will have to take a look at the other products and services you provide and understand what are the trade-offs between them and the impacts of reduced production." (*Int. 14*).

As widely acknowledged, servitization features support profitability growth and expansion of customer base. "A benefit that rental and sharing initiatives surely entail is the approach towards a different type of customer, which perhaps wouldn't even buy such products, because too expensive", as unfolded by VF. "The case of 'Rent Your Kipling' is for instance the addressing to a new younger consumer, who probably didn't consider Kipling as a brand of reference. Thus undoubtedly there are great opportunities and our pilots serve as drivers for a supply chain wide shift in the way business are organized. Our objective is to transform these projects into prominent revenue sources by 2030. Furthermore, since the customer of 'Renewed' products is different from traditional ones, there are no significant criticalities in connection to cannibalisation aspects in this moment. Moving forwards there will probably be more but at that point the 'Renewed' product lines shall be developed enough to compensate. These innovative models are the future of how things shall be done, hence it will inevitably necessary that traditional business lose for the benefit of new ones, similarly to what happened with the advent of the digital era." (*Int. 6*).

In these regards, Chemical Recycler X points out the critical role that chemical recyclers can play in closing the loop by recapturing all those resources which cannot be used anymore or are currently disposed: "Our technology may offer a valuable solution to brands to continue to run their businesses successfully and sustainably to contribute UN's SDG and deliver against their targets formulated in the Fashion Global Agenda. On the side of feedstock suppliers, there is huge business potential, since currently around the 50% of textile waste collected is not resold and constitutes a burdensome problem for collectors, both logistically and financially. Within these unprofitable resources, 20% goes into down-cycling for a trifling value and 10% flows towards landfill and incineration for which ponderous disposal taxes have to be paid. Hence, our technology could resolve their economic loss, while enhancing systemic value for the whole industry." (*Int. 12)*.

Furthermore, referring to complete sustainability consistency, it shall be remarked how lean up processes are actually in place among the majority of actors interviewed, mirroring the statements of the Reverse Resources report and the supply chain requirement exposed in **Section 1.2.6** (Bruce, Daly and Towers, 2004; Abtan, Bellaiche and Vahle, 2013; Reverse Resources, 2017). For instance, Candiani asserts that they actively worked not to have overstocks in

order to work in a pull system and send most of the waste types to various forms of recovery, minimizing the volumes ending in disposal scenarios (*Int. 5*). In turn, Brugnoli minimizes overproduction through a "late personalisation approach, thus we do not produce stocks of tinted fabrics, but we rather work upon requests". (*Int. 3*)

Similarly, within Orange Fiber organisation "the objective is exactly the overall zero waste. Thus we are working with the R&D department in order to eliminate production leftovers even at a larger scale". In this case, it is also possible to discuss about waste minimization through biodegradability. In fact, "Orange Fiber textiles act as traditional cotton, silk and elastane fabrics present on the market, thus they may be returned to production processes, as H&M is doing with cotton and polyester. Still, more relevantly, our fibre originates from an organic material as citrus fruits pulp and is therefore biodegradable through a special industrial composting process." (*Int. 2*)

The fashion industry may verily represent a critical market for a widespread sustainable revolution, as supported by the analysis of the "Financing the Transformation in the Fashion Industry" (Fashion for Good and Boston Consulting Group, 2020). The full adoption of circular economy may be pervasive both in terms of number of companies willing to follow and drive the trend, but also in terms of other industries and economic agents influenced. This refers to the diverse application of circularity principles throughout the whole supply chain, i.e. from the use of a dyestuff synthesized from cotton field waste as sticks, stems and so on, till the optimisation of international freight forwarders' flows exploiting excess space in shipping containers and a network of remanufacturing hubs (*Int. 5*).

There is indeed an immense improvement gap that may be filled with the innovations brought by the widespread implementation of digital technologies. According to Centrocot: "The greatest issues that we see is the identification and traceability loss in the moment an item is sold. Industrial waste flows are a big problem but still they are manageable. Post-consumer waste, on the other side, represents a systemic loss of information and value. Hence, it is then necessary to understand which material it is, which chemical products were added and in some case which processes the item had undergone during its life cycle, but the level of uncertainty is clearly high and this widely raises costs." (*Int. 10*).

2.3 *Need for collaboration*

The multifarious and cross-sectoral impacts of the circular fashion transition further load the necessity for solid collaborations among the totality of game changers involved in both incremental and disruptive innovations.

At Lenzing there is a diffused feeling "that without collaboration the company would lose competitive advantage, by hampering the growth towards the two strategic pillars of sustainability and innovation" (*Int. 1*). At Candiani the answer is likewise clear: "Regarding the most relevant opportunities of development, I would say collaboration absolutely, specifically because of where we're placed in the middle of the supply chain. I think that especially in circularity we have to join efforts, so that each initiative is synchronized and get to the optimal outcome/value" (*Int. 5*). At Orange Fiber, they put collaboration among stakeholders among the prominent drivers for the effectiveness of the circular transition: "The factors that might accelerate the evolution are on one side financial, on the other synergetic: alone it may be possible to move faster but the road travelled will be very short. Establishing virtuous cooperation partnerships, it is possible to truly achieve much more, integrating top competences for each phase of the process" (*Int. 2*). At VF: "Collaboration is of absolute strategic relevance because it is necessary to integrate and let communicate different parts, since every actor always wants to go his own way but there are actually already some concrete instruments on the markets that could be used. This regards mainly methodology, where the different models of the Higg Index already entail some assessments that could be put into practice." (*Int. 6*).

In respect to operations, the most emblematic example comes from MUD Jeans, which applies the true sense of pre-competitive collaboration aimed in the Pulse of the Fashion Industry Report 2018 (Lehmann *et al.*, 2018). The Dutch CEO unfolds: "We don't want to go overseas because it is not sustainable to maintain the circular business model so far using shipping. If some stores in the US ask us we don't say no but we discourage to send back the stuff to Europe to be recycled. We would like that other companies take our blue print and start similar businesses there and we're open to help them start up and give them our insights but we're not interested in starting on our own." (*Int. 7*) This integrity mirrors a valuable strategy to drive the whole industry development even long further than company boundaries, spreading the message in a deeply influential manner.

Another interesting case comes from Circle Economy, which disseminates theoretical knowledge and best practices to achieve the same objective of MUD Jeans on a wider scale. For instance, one project regarded the improvement of denim environmental performance: "We have also worked in the Denim Alliance with denim mills, cotton recyclers and denim brands together to be

able to integrate post-consumer recycled content into their collections. There were around 20 organisations working together and developing 45 new types of fabrics. Interestingly enough, some of the companies are still using those fabrics in their collections, even representing the core of their offer now. (*Int. 14*) This demonstrates how even small integrated efforts may achieve widely distributed and valuable business effects.

In order to spread even more the adhesion to circular innovation, online platforms act as facilitators and accelerators of the synergetic interconnections needed to push the whole system towards the alignment with 2030 strategic SDGs. Consistently, as Centrocot states: "The lack of knowledge is what stimulates the creation of information collectors in form of digital exchange platforms or databases. For instance, a platform as M3P will soon further benefit from the plug-in with other databases, as for instance the one referred to the official recyclers for each material in each region" (*Int. 10*).

In these regards, it is important to underline the potential of these platforms in the definition of the flows redistribution logics.

2.4 *Open vs Closed loop debate*

Specifically, the Circle Economy interviewee exposes: "I think these platforms have the potential for both open loop and closed loop solutions advancement. I would say nowadays it's easier to re-enter in open-loops in other industries because there are already solutions to scale for that and there is a market (e.g. down-cycling for insulation materials or the automotive industry). Still, definitely there is high potential for closed loop as well, there are just many uncertainties in the market right now that need to be addressed before this reaches scale: among these there is the readiness level of technologies and the chemical content or other potential contaminants in post-consumer waste, where every batch is different so you don't know where, how and with which exact materials they were produced. These issues need to be solved to understand how to put a price on materials and define what type of applications they can have later on. (*Int. 14*)

At VF: "Recycled flows are currently almost completely open-loop because the only technology enabling an upcycling of textile products is Nylon 6, to which many brands shifted because Nylon 66 is not recyclable. We partly use Nylon 6 supplied by closed-loop recyclers but often it happens that these will mix a share of textile fibres with another of fishing nets, rendering the percentage of closed-loop supply not always reliable and indicative. Generally, we

encounter a large difficulty in employing recycled cotton. We're working on it but the problem relates to the durability, since the fibre once recycled is cut in shorter staples. Basically there are ongoing projects, but as long as there won't be an industry level scalable technology to transform cotton into new cellulose or to recycle polyester it won't be possible for closed-loop options to reach significant shares in material mixes." (*Int. 6*)

This especially mirrors the current state widespread dispatch of resources towards their end stages in the form of mattress stuffing, wipers or insulation materials. Digital and physical solutions for these issues are for now still wild chimeras difficult to control and rely on. Anyhow current limits and lacks shall serve only as suggestion for future innovation and system design in order to contrast any type of unsustainable growth direction.

Denim is a particularly indicative case to examine. MUD Jeans states: "The more difficult part is about post-consumer waste, namely about recovering old jeans and reusing them on the same functional level. Now we're studying together with other promoters of the circular economy how to go to 100% post-consumer recycling: we're researching to see if we can chemically recycle part of the cotton in order to exploit the longer fibres that when brought back to pulp can make out better yarns. On the other side, there is a fiscal issue regarding the part of the yarns which is not usable for denim, so we are going to mix that with mechanical recycled ones in order to maximize total value recovery. Hence, employing both techniques together we think that we can reach our objective." (*Int. 7*).

In accordance, also Candiani Denim remains unsatisfied with the current state of the recycling technologies because "they create a more cellulosic fibre, it's not cotton–to–cotton recycling. So we're exploring true closed-loop options. We need that since cotton is our most relevant raw material and also one of the inputs with the greatest environmental impacts." (*Int. 5*)

In these cases, the breakthrough of chemical recycling technologies may actually change the rules of business and production logics.

2.5 Chemical recycling debate

As mentioned above, the formulation of industrial systems and supply chain networks around molecular recycling development shall in any case follow the principles entailed in the waste hierarchy and in a completely consistent company policy devoted to sustainability in each single process, resource or employee. A thorough analysis shall thus be carried out before the development or employment of any recycling business strategy or facility.

Circle Economy's interviewee specifies: "I think you definitely need to assess the trade-offs among land and water use for virgin against energy use for recycling, also in the specific context of where the recycling is happening and which are the environmental impact of that region as well. I definitely think there is a lot of potential for chemical recyclers. Especially if you notice the way today manmade materials are created and the fact that many recycling processes resemble those production processes, it is a logical consequence that if you can make more sustainable those manmade fibres' processes I would say you can make also recycling processes more sustainable. An example refers to Lyocell production which also reuses dyes and chemicals. (*Int. 14*)

Comprising a wide spectrum of hard-tech innovations, this evolution will require more time, investment, "specialized skill sets, customized tools and orchestration of a wide set of stakeholders across the fashion supply chain" than other digital technologies currently on the edge (Fashion for Good and Boston Consulting Group, 2020). "Thinking about recycling technologies, the usual estimation is in the next 3-6 years, with some technologies already being at pilot plant scale others more at demo-plant level." (*Int. 14*). Some of these are even starting to escalate in the present. Renewcell states: "We're actually commercial now since we already sold a number of batches and clothes will be in retail in the first quarter of this year. We're planning to expand capacity as soon as possible so we will start building the second plant at quarter 3 or 4 this year." (*Int. 13*). This is possible especially in the cases of cellulose- or polyester-like fibres, for which it is possible to refer to already existing processes and adapt them to the specific need. Furthermore, this is supported by the global demand characteristics. Chemical Recycler X offers a broad classification of fashion industry waste: "Analysing the textile waste collected we apprehended that the majority of compositions present contained pure cotton, pure polyester and poly-cotton blends." (*Int. 12*).

Accordingly, these factors together help to ease the path towards a fully closed-loop fashion system. Responding to high quality standards, Lenzing currently uses mostly pre-consumption materials but agrees at the same time to set spurring targets for the near future: "For the Refibra process, we get to a pulp of waste materials (30%) and this is then blended with virgin wood pulp (70%). By 2024 we want to use 50%-50%. For commercial reasons, in large production we still use 30% pre-consumer, 0.5% post-consumer (we did only one collection last year), the rest is from internal Lyocell production." (*Int. 1*). Always in the field of cellulosic pulp, Renewcell manifests their thrust for excess consumption exploitation: "I think the current stock that we have is 25% post- and 75% pre-consumer waste, but we've already done a lot of batches with just post-consumer waste." (*Int. 13*). Also EVRNU foresees that 100% post-consumer recycling will be possible with their all closed-loop process, which reuses chemicals as well (*Int. 11*)

Accordingly, Chemical Recycler X further elucidates the role of these technologies for a sustainable improvement for the whole industry and points out the need to work on solutions for the issue of post-consumer waste contaminations: "Potentially our process is able to take it post-industrial, pre- and post-consumer, for this initial phase we decided to focus on eradicating the post-consumer textile waste, given the entity of the problem and the interest of society and stakeholders looking for valuable solutions. Our polymer recycling process is indeed able to separate and decontaminate, thus eliminate dyeing agents and contaminants coming from the textiles production process (eg. finishings, softeners...)." (*Int. 12*). On this aspect, Renewcell sheds some light on the resolution that use phase traceability may feature: "When it comes to chemical content of incoming materials, we do several testing of the materials before we get them and of course try to understand as much as possible about it from our suppliers. To some extent it's possible for us to handle it if there are specific chemicals in it that we are aware of. In these cases, we can do some changes to the process just to be able to treat those resources in a way so that the process wastewater is acceptable for water treatment." (*Int. 13*)

Still, the lack of transparency and technical means further diversifies in manifold barriers that hamper the desired outcomes and full circularity adoption.

2.6 *Closed-loop fashion barriers*

These business evolution hurdles may be mainly subdivided in 3 categories:

a. ***Systemic – cooperative***

First of all, there is an issue of rebound effects incorporated in the general concept of circular economy, since each time resource efficiency is gained, this might eventually also cause enhanced levels of consumption and therefore production. Thus Brugnoli strongly supports the relevance of waste prevention and minimization, suing other companies that ride the wave of green washing or even stimulate an expansion in waste creation: "Our objective is to move forwards and raise the production of ever more biologic fibres, thus eliminating overall wastage. However, we notice that on the market there are initiatives, which do not exactly stand on the side of true sustainability, since they incentivize greater volumes of clothing excesses. On the contrary, for Brugnoli innovation is not a process of rebranding in green labels something that was already done before; it is rather producing

novel raw materials with a globally sustainable productive approach. Accordingly, a fundamental step has also to be taken in the education of consumers." (*Int. 3*)

Secondly, particularly for chemical recyclers but not only, there is the complexity to push forth an innovative technology which doesn't perfectly match with the prevailing system's organisation and which doesn't have an already existing market. In Chemical Recycler X words: "Here we have to shape an industry that may accept and valuably employ the technology. We need to merge two supply chains. Among these, the part of textile collection is still scattered, both regarding the textile collection and aggregation and also regarding a local, regional and European legislation that may favour higher collection levels by educating consumers. On the other side, the textile value chain still lacks of receptiveness for a product like ours. There is a great misunderstanding concerning what shall be identified as "recycled", "sustainable" or "circular". Thus, the question is: even when we have a marketable product, how will we commercialize it within the fashion supply chain? Will it become a recycled or a circular product? Presently there are no factual definitions." (*Int. 12*).

Following the fil rouge, Lenzing adds: "From the point of view of the overall concept, I think we're missing standards which are worldwide or at least in the European Union. Now every Member State has own standards for waste declaration, for import and export of materials so it gets really difficult to trade and work in a global way. Just as an example the import of recycled materials into China is very difficult and also in Turkey it's not even aloud for the textile market, so it's really a huge barrier." (*Int. 1*).

The requirement of interoperability of standards further complicates the regulative function that policymakers need to fulfil in order to lay the base for any virtuous closed loops to scale up successfully. Consistently, Candiani enlightens the requirement of diffused infrastructure and cooperation for the sake of the effective development of the technologic means for the transition: "Regarding the barriers against the circular development, I think first of all the technology is not there or better the infrastructure is not in place. It seems that there is a growing interest from policymakers but I feel we're just at the very beginning stage of that. Again true circularity is an issue, also because we're in the middle of the supply chain, so it would require the collaboration of the brands and it's not that the interest is not there but what is limiting now is the recycling technology." (*Int. 5*). Also Evrnu points out the lack of collaboration and the changes requested to brands, which ask for sustainable materials but which then do not fully support innovation processes (*Int. 11*). As mentioned in the literature review above, designer

and retailers actually play a fundamental role in pulling and pushing disruption both upstream and downstream. In this regards, the collaboration between VF and the Ellen MacArthur Foundation and other players is developing the definition of concepts as 'durability', 'recyclability', 'traceability' and so on for each material category in order to define in the end the circularity level of an item. "This is an effort made at industry level, it has no sense at firm-level because it needs to be acknowledged in a widespread manner." (*Int. 6*).

Furthermore, cooperation shall also be demanded from the logistic perspective. Candiani further states: "I think that on the demand side there would be absolutely no problem. Again it is a matter of logistics and how to build up the system. So it is really a matter of how to get back the materials also because we have a strong presence in US, other European states and growing share in China." (*Int. 5*). Especially in regards to reuse models, VF states: "Where active, our take-back programs currently collect all sorts of brands also externally to VF, in order not to create an additional hurdle to the consumer, because the complexity level in retrieving each item to the specific brand would increase a lot. What is more interesting according to us is an industry-wide transition towards effective recycling technologies, where recyclers themselves recollect and sort the materials and we directly recover the output at the end. At present, generally 30-35% of the recollected materials is to be recycled, but until product design won't change, this percentage will need to go into down-cycling for the majority of clothes, since traditionally products are designed with an unmanageable mix of fibres and colours. Hence, in some cases, we have to do investments along our supply chain in order to develop adequate materials. For instance, the case of the Napapiiri 100% recyclable Infinity Jacket is emblematic: it required 3 years to study and develop all nylon 6 fabrics, trims and zips that would pass the quality test, among which the most difficult part has been the filling because traditionally it has always been either down or polyester. Hence, there are issues that the industry is demanded to confront with: either we simplify in an absolute way the design of clothes producing only basics or it is necessary to find alternative solutions especially for the most complex clothing items. In this moment it is widely a question of design but it is also a problem of an industry that didn't keep a proper pace of innovation in technologies and materials for far too long. There still never happened a Copernican revolution for which every player starts strengthening circular design and solutions." (*Int. 6*).

b. ***Financial***

As expressed by the majority of interviewees financial constraints are particularly burdensome for sustainability and circularity oriented companies. According to Chemical Recycler, "the barrier which numerous players surely find is the difficulty for these technologies to scale up and become commercially viable, in the sense that there is the wide necessity for a great amount of capital and resources which shall derive from stakeholders with the same mission." (*Int. 12*). More in depth, Renewcell clears up: "For sure, financing is challenging for a newly established process industry such as ours, since we're very hardware oriented, we need machines and employees, which is very different from building a software company, since it is much more capital intensive. So it takes a while to get that up running. It's also expensive to acquire post-consumer waste, since it's a manual sorting process. Then of course it is a matter of design for circularity among the brands: they need to become much better at considering end of life for their products, so that we can handle it more easily and conveniently." (*Int. 13*). MUD Jeans continues: "Among the barriers for circular start-ups I would mention mainly financing it all, in setting it up and managing it. All the steps for sustainability (fair wages, non-toxic materials, social responsibility…) demand a little bit more investment and so the costs get much higher than your competition and the margin is lower because you cannot sell more expensive, so it gets difficult to have budget for marketing and investment." (*Int. 7*).

Higher costs relate also the inefficient scale at which these start-ups produce. "We are a small company and therefore we buy only small quantities which is already a disadvantage for us: in Recovertex they like to start the machines and make 100.000 yards, for us they make 10.000-20.000 yards sometimes, even if the orders are growing now. We mainly need volume: we buy our denim now for around 5,5€/ya but if we would have 100000 yards it would be at least 1€ cheaper and we are getting there slowly. (*Int. 7*)

Moreover, in most cases, there is an imputable high degree of innovativeness of the manufacturing process and missing references to resemble. According to Orange Fiber: "The greatest obstacle has surely always been fund raising. From the point of view of product acceptance on the market, we find maximum openness both among consumers and potential industrial partners. However, given the disruptiveness and dissimilarity of our process, each circular investment in machinery or technologies will have a quite weighty economic relevance." (*Int. 2*).

All these expenses-raising factors sum up with the unpreparedness of the market, thus "the struggles are that you're doing something that 80% of the population doesn't understand and most people still buy clothing

being price-driven." (*Int. 7*). Brugnoli specifies how in some cases it is possible to lift the price because of the more precious production inputs, but on the other side it is often necessary to depress the margin in order to offer an article which may have sense on the marketplace (*Int. 3*). Accordingly, Candiani unfolds: "We're lose competitiveness because of where we produce. It's complicated but we're trying to compete on quality and sustainability. I think we're in the middle of the transition of the industry so hopefully we just have to wait it out, so that we see the tipping point where the market favours us." (*Int. 5*).

Generally, it is widely acknowledged that top-down regulative supporting initiatives will embody the acceleration of sustainability champions and the appeal towards the bulk of late movers. In these regards, MUD Jeans' CEO offers a key example: "On the competition side there is no comparison: between buying and selling there is no levelled playing field so I'm asking the government to give us a special VAT rate, because when we recycle jeans and we use 40% post-consumer waste in my thinking I should be able to give my customers 40% discount on the VAT because that is already been paid on those jeans" (*Int. 7*).

In these regards, according to European dispositions and instances presented by Rete ONU, the Italian Camera Dei Deputati already initiated the process related to new reuse and recovery laws in which VAT will be reduced to 10% for all used clothing sector operators (HUMANA People To People, 2018).

c. ***Technical***

Finally, referring specifically to the fashion system, there are a number of issues regarding technicalities of textiles characteristics and related flows management to overcome. For instance, "one of the most relevant barriers for closed loop fashion for recycling is the extreme amount of different materials used in the textile industry, the dispersion and diversity of fabric plants and the inaccuracy of labelling in garments (for example it does not show materials with a weight less than 2% and also all sewing threads or trims or other specific materials are not covered there). The second barrier also relates to the material itself because you don't really know what kind of chemicals has been used neither in the production process nor in the use process." (*Int. 1*). These aspects further contribute to the hindrance of recycling's economic and environmental sustainability. As MUD Jeans remarks: "Technical barriers are about the use of post-consumer waste because it is more difficult to create qualitative yarns and it is more difficult to weave." (*Int. 7*). According to Centrocot: "At the moment, it still unfeasible to control how many times an item was recycled. In some

cases, it is even difficult to check if the material is virgin or recycled at all, mainly due to technological difficulties and a general lack of equipment" (*Int. 10*).

Furthermore, due to the disorganisation in the infrastructure and the whole system, it is often possible to encounter stumbling blocks in respect to materials supply volumes and quality variability. Candiani states: "Last year we produced 30.000 meters of 100% pre-consumer recycled materials so in comparison to our total it's not huge but again it's based on demand and it is in the beginning phases, additional to the fact that volumes are limited by the quantities of cotton that we can recover." (*Int. 5*). Thus, it is apparently still quite complex to optimise the network and stabilize virtuous industrial relationships for a solid continuous supply, demand and generally innovation development. In particular, another comprised issue reflects the degradation of textile fibres re-entering the loops. Renewcell affirms that theoretically the cellulose pulp may be recycled infinite times, but that "considering the benchmarks in recycling it's probably 5 to 7 times." (*Int. 11*). Thus, further detailed studies shall be carried out in order to determine more quantitatively the impacts of diverse levels of speed in degradation on the effectiveness of closed-loop textile systems.

Besides the criticalities of recycling, also the business models based on reuse shall be structured in order to favour efficiency in logistics and educate consumers for easing durability. Indeed, MUD Jeans explains: "Repairing is very expensive because we do it here in Holland with a social enterprise in Almeer, thus considering also shipping back the goods to here and then delivering to them. It is extremely expensive but we feel it's part of our mission. Anyway, locally the quality of jeans is very good and we don't need too much repairing but only sometimes people exaggerate (sending them back to repair 5 times a year)." (*Int. 7*). Also according to VF "repair systems performances depend upon each country. In the US for instance it is easier because the legislation is homogeneous and the same service may be provided in all States. In Europe instead there is much more fragmentation and in order to render the service effective at technical level in the projects implementation it is necessary to have one partner for each country, leading to a great number of partners. Furthermore, there is a regulative problem regarding the handling of these goods since we are not allowed to move them because we are not considered recyclers." (*Int. 6*)

Luxury brand X further adds: "Repairing in luxury is quite difficult, it could be viable for the most expensive garments but generally it is complex to create rental or reselling programs without hurting the idea of quality and strength of the brand. We don't need it." (*Int. 8*) Hence, also a strong program of strategic reorganization and rebranding will

be fundamental to actually drive profitability growth for these business models.

Finally, aiming at enhance, customised service levels and higher traceability levels, during the use phase it is still fundamental to respect certain boundaries. As Centrocot unfolds: "The main hurdle related to RFID is the undermined privacy of the consumer" (*Int. 10*).

Aside from direct supply chain hitches, the revolution of the fashion system shall begin from the restructuring, optimisation and incentive of the reverse supply chain.

2.7 Current EOL issues

End-of-life management of materials lacks indeed of organization and efficient processes. According to Circle Economy: "The business case for collectors and sorters today bases itself in being able to sell as much as possible garments in the second hand markets, because their financial gains today come from the reuse industry either locally or exporting. One thing which is really unbalancing their business case and shrinking it is the fact that they seem to recover each time more volumes that they can't sell in second hand markets and this has to do on one hand with the increased disposal of garments (shorter cycles) and on the other with the lower quality in textiles themselves, but also because the second hand market is now starting to become saturated." (*Int. 14*)

Deepening the drivers for second hand demand, the analysis should follow international macroeconomic considerations. "The less a nation generally consumes, the higher will be second hand prices. Products which are not possible to be sold here at a sustainable price, become economically sustainable in states as Bulgaria. The more accurate sorting phase will be thus carried out in hubs near these end markets" (*Int. 9*). Consequently, second hand is for now naturally low in developed economies and the majority of used clothing flows continue the pilgrimage towards less developed countries in Eastern Europe or especially in Africa and Asia. In this respect, the Fibersort Interreg NWE project adds: "Regarding exporting, first of all we're missing data because we can't really assess what is happening in the international markets regarding the exported textiles. Secondly we need to understand what of what we export is actually sold in the second hand market there, what does it actually foster within the local economy (employment and financial gains), but you should also

take a look at what are the downsides, which industries are not being developed because of that and also how much volume of textiles is not being sold as second-hand and what happens to that portion, since in most these countries there are no waste management schemes for separate textile collection. Thus exporting can also mean shipping synthetics to stay in a landfill in another country for 300 years, so in this case this needs to be solved" (*Int. 14*) This concrete hurdles clearly scan the issues related to geographical burden shifting mentioned above.

On the other side, exporting supporters claim that the expansion of boundaries actually enhances value redistribution effectiveness. Rete ONU unfolds: "Second hand operators affirm that without used clothing resale there would be no access to such a primary good in those countries. Local apparel manufacturers object that such low prices for second hand clothes inhibit national economic development, since they cannot rely only on exporting their articles to other nations in order to survive. But when some countries decide to ban imports of used clothes, often it is in order to encourage the invasion of cheap Chinese clothes than to favour the local textile economy. Solid solutions to these contradictions are necessaries. Circular economy is not compatible with the repression of reuse free market, and development should be designed to be perfectly compatible with reuse. Actually, in the importers countries the second hand clothes distribution value chains guarantee more jobs than the new clothes value chains." (*Int. 9*).

Thus, it will be fundamental to act both in the direction of consumption reduction as also of enhancing the viability of alternative solutions for the excess volumes which are not manageable with reuse options. Legislation and regulation policies are required to support the fluency of business choices for each supply chain player in accordance with the following of the waste hierarchy, finding the best end-of-life management model in relation to the characteristics and degradation conditions of the materials. As the Fibersort Interreg NWE project interviewee unfolds: "There will need to be more standardisation also for export and trade, if you're discussing what is no longer waste, also regarding the criteria for considering it a secondary material to be re-entered in a production process. Ex. You will know what characteristics the textile has and you will be able to export it only if the importing country is able to process it" (*Int. 14*). This calibration action shall indeed minimize the issues related to geographical and intra-sectoral burden shifting of the economic and environmental impacts.

In these regards, the current obligations for collectors (in Italy) symbolize a foundation for the development of standards and norms, yet they do not support the further addressing of wrong allocation or exporting issues. "For the law, it is mandatory to distinctly classify all types of stocks in collectors and sorters warehouses, otherwise it is possible to incur in penal issues. Already selected goods will become "Non-waste" and will then be classified as "Second

hand" or "Second raw material" according to the destination market and the recovery channels. At commercial level, the macro-categories are: "Reusable" (ca. 60%), "Suitable for other forms of recovery" (ca. 30%) and "To be disposed of" (ca. 10%). This differentiation of flows reflects the one mandatory by law, since everything which ceases to be "Waste" then need to have a clear output declared. Within the "Reusable" grade, there are numerous different sub-classes depending on the market and on the classifications of wholesalers." (*Int. 9*). Whereby, the level of accuracy requirements varies a lot and standardised partition of flows is still not a widespread practice across the whole worldwide value chain.

In order to solve the issues of end-of life-management, it will be convenient to exploit different technologies to facilitate the processes of standardisation and the diversification of materials and flows. Still, the preparation level is immature. Rete ONU members have collaborated in various projects for sorting technologies but the problem always remains the precision in contract to a human classifier. This affects then also economical returns, since "in these process the Snowflake principle should be taken in account: i.e. the more detailed the classification is, thus the more it's possible to approach a unit of piece per piece, the more the price may be raised." Hence, "in respect to innovation, the major priority concerns the ability to transform as soon as possible the existing pilot-technologies into mature options in order to respond to the requests present on the market, reaching an adequate scale. This because, despite the proliferation of solutions, economic sustainability keeps driving the displacement of goods towards countries like India or Pakistan where substantial problems regarding environmental standards subsist." (*Int. 9*). These evolutions might indeed help to push circular value maximisation, by shifting demand patterns for what regards the reuse of clothes or their fibre-to-fibre recycling.

On the other side, supply patterns are changing as well. Rete ONU states that: "Now, because of fast fashion, the products turnover is increasing and therefore clothing waste volumes are lifting up. Consumers get rid of goods much faster than before, thus collection costs rise but the reusable portion declines staggeringly both in volume and in value. Under these conditions, the interest for the reusable portion grows, driving harsher bids in the tenders for the assignation of the collection service, and with the amount of reusable portion obtained it is then necessary to pay all costs sustained in the recovery supply chain." (*Int. 9*)

Specifically, the costs keep shooting up. For instance, "the output to be disposed of is a "special" waste type and the related disposal costs have grown relentlessly. This functions as driver which gives the impulse to all recovery systems, as happened with the common differentiation of garbage at home. Generally, there are no defined prevailing parameters which determine the international markets prices nor the cost schemes. Thus, partly basing on

reality, the belief has spread that who recollects textile and clothing waste is able to sustain its own costs by reselling the reusable fraction. However, since disposal costs are increased, the reusable fraction diminished, the quantities to be managed multiplied and since no profitable recycling channels exist in the post-consumer stage, the joints for the overall equilibrium are now loosing up. Extended producer responsibility may thus offer that quid necessary to restore those structural management requirements." (*Int. 9*)

Worsening the situation, there is the fact that municipalities offer no financial yields to collectors and do not control their output flows. Indeed, "Sorters and collectors respond to municipalities which tender the collection permits. The contract is now praised based on price payable and quantity collectable. This means that the kind of only parameter used is quantity and no-one is asking what collectors do with the textiles at the end, so to really analyse their local resale and exports. This is not within any regulation or policy agreement, so really getting that question into the scope of the tendering process might really make a difference" (*Int. 14*). Furthermore, Humana specify more in depth: "Rete ONU specify more in depth: "For generalized practice, the collection of urban textile waste is a service which doesn't get paid by who has the public responsibility to collect waste. In fact, the municipalities, as public local administrations, in most of Europe have the responsibility to collect all urban waste types but they also have the exclusivity upon these. Being waste their property, they are allowed to transfer their ownership to urban waste collectors which are responsible to guarantee a correct destination for the waste collected. Then, the owners of the recovery plants have to guarantee a correct destination for the "special" waste that cannot be recovered Since the sustainability of the whole system depends on the balance between re-valuable and non-re-valuable fractions, if the public ownership of the whole flow wouldn't exist, there would surely be some organisation recovering the whole reusable fraction, disregarding the rest. On the other hand, the public ownership of the textile waste was becoming a tool to squeeze money from collection operators through even more greedy auctions, since there has been a falsely diffused belief of profitability present in the sector" (*Int. 9*)

Dynamism along the reverse supply chain will likely keep rising, also in relation to more stringent and precise regulative evolutions. "According to the Directive 851 of 2018 of the European Circular Economy Package which modifies Directive 98 of 2008, it will be mandatory to recollect all used clothing by 2025 in all European Unione Member States. Then countries of Eastern Europe like Poland or Romania will start to put in the market growing flows of second hand clothes, that will sum to the growing flows coming from South Korea and China. This trend will cause an overflow of apparel volumes to be managed. Probably second hand market will absorb everything, but the break-even points will depend even more to the existence of solid channels of recycling. In this regards, it will be necessary to work on the technological questions but especially on the economic viability, since current pilots didn't

demonstrate to possible imply interesting markets. Still, it is important to always recall the fact that the Directive 851, very correctly, strongly pushes the principles related to eco-design, favouring product reusability and only secondarily recyclability." (*Int. 9*). These factors will resolutely drive an enhanced stakeholders' interest and possible valuable business case around old apparel recovery.

"The financial sustainability of sorters and collectors, their business model is on reselling the reusable part and basically they're paying a cost for everything else. In these regards, the idea of automated sorting technologies is that this portion of textile which cannot be reused enters a different market, where you can sort it based on the material composition. The biggest differentiator for these technologies is that they can sort at a very high speed with a very accurate outcome, so you can generate a really reliable feedstock for recyclers. The accuracy depends per material: testing the identification >95% cotton textiles then selected and diverted into the "pure cotton" bin, a 97,5% accuracy has been found; other materials have a bit lower levels but it's part of the Fibersort Interreg NWE project to try to solve these issues and optimise the technology for commercialisation." (*Int. 14*)

Finally, at this point it shall be straightforward that sustainable fibre-to-fibre recycling may represent the solution for the enormous mass of textile flows which currently flow into low value high pollution end stages, still it shall always come after the optimisation of prevention and reuse models.

2.8 ***Recyclers' issues***

Hence, the review of findings shall now focus on a subset of interviewees and carry out an analysis of the present factors and possible stumbling blocks determining the type and speed of expansion of open- and closed-loop solutions providers, in order to understand the validity of incentive programs in support of their business case. Success will definitely depend upon economic convenience principles, given a quality level compatible with market standards. The business opportunity will in turn depend upon demand growth trends and cost optimisation patterns while scaling up. Some examples have already proved trustworthiness.

On the demand side, drivers relating to traditional fibres' supply technical boundaries and rising prices are likely to gain relevance in a consistent direction and there subsists wide consensus regarding a positive growth trend. Thus, "there is an apparent increasing demand in the textile industry but the

supply from traditional fibre sources will become more and more costly and risky, while there will be consequently an impressive boost for those materials produced from alternative fibres." (*Int. 2*) Similarly, Brugnoli states: "there will surely be an expansion in sustainable raw materials, the recycled options first because they are easy to produce, the biologic options then." (*Int. 3*). In accordance, Chemical Recycler X further specifies: "Generally, the trends comprise a scarcity in virgin resources, which will likely spur prices up and cotton is already now a glaring example. Our objective is to offer a competitively positioned product, because we confidently know that brands won't be prone to spending much more, despite there are many reports asserting estimates of consumer willing to pay 10% more for sustainable products. In reality the logic joints between consumer demand and brands demand doesn't always function so well. However, the industry will form around the pricing of input and output materials as soon as it will be understood that our technology can generate new value streams across the two textile supply chains." (*Int. 12*) Finally, also EVRNU supports the hypothesis of a "global shift in pricing schemes for environmental and social responsibility" in the near future (*Int. 11*).

It will surely be a step-by-step progress. According to Lenzing: "At the moment, recycled raw materials are at least 50% costlier than virgin. We believe it will go down: for example, in recycled polyester they started with premiums of 50% and now they are down to 10% or maybe even nearer to cost. So I think it will go down but still it depends, I believe they will always be at least equally expensive if not even more than traditional ones, still in 5 years. Particularly economies of scale can play a relevant role, I would say from 10.000 tons to a 100.000 we talk about 50% cost reduction, thanks to the economies of scale." (*Int. 1*). Consistently, Circle Economy states: "I would say in order to make recycled materials more convenient you will need a lot of scale first but also financial support, because until virgin raw materials are priced as a scarce resource I don't think they will reach parity without any incentives from the regulatory side: for example, tax reductions for products with the recycled content or products in the second hand market." (*Int. 14*). From the side of the recycler Renewcell: "There is no reason to not transition, if the quality is the same and the price is equivalent. Our target is to get price parity, thanks to the fact that as we scale up we have beneficial economics especially due to the fact that we're working with a raw material that's low in input value. Since we use cotton waste fabrics which are basically pure cellulose we have a process efficiency advantages. So we have a very competitive cost structure." (*Int. 13*).

Similarly, Orange Fiber affirms: "At the moment our fabric is comparable, in terms of price, quality performances and end use, to an excellent silk from Como. Our price averages around 25-35€/meter and is thus aligned with the objective to erode the traditional silk market replacing it with a much more sustainable option. Further on, trying to exploit at maximum scale economies,

we'll be surely able to render even more competitive our product penetrating new market segments, other than luxury." (*Int. 2*)

These examples show that, under specific conditions of the products offer and the implementation process, there are already business cases that entail a great viability beyond the overcoming of scalability and marketability barriers. These possibilities are further amplified by the application of innovative business model also on the side of technologies and machinery developed. Chemical Recycler X for instance explains how they will move forward into commercialization. "We are a technology licensing company and our customers, the future plant operators will commercialize the outputs on the market interested." (*Int. 12*). Likewise, EVRNU consider leasing a "fundamental part of their business model" (*Int. 11*).

Anyhow all these efforts will lose consistency and value if they won't find the support of a responsive regulative body and an acknowledged end consumer base. As VF specifies: "The customer surely understands the concept of 'recycled' even though the expectation is that such an item shall cost less in respect to a completely virgin item, which is often unattainable because there are diverse costs which push the price towards the one of traditional products." (*Int. 6*). This may lead to a stagnation of the innovative fibres market hampering the improvement of the whole reverse value chain.

2.9 *Consumer awareness*

As VF unfolds: "Sustainability in clothing is a very complex topic for consumers. The experience of the case of the Infinity Train shows us how generally the customer struggles to see the jump that this type of item brings on the market. This is all because he or she is not conscious of the complexity neither of the industry nor of a garment. Unfortunately, fashion has become a commodity and consequently also clothes are treated as commodities, against all the investment in R&D necessary to offer these rather sustainable or circular innovations. Accordingly, until there won't be such a type of sensibility and conscientiousness in a widely diffused manner among the population it is quite arduous." (*Int. 6*). Similarly also for Brugnoli "the most relevant opportunity lies in educating the consumer. With the rise of the millennial generation the requests for sustainable products will swell, but we shall be careful for diffused carelessness. In this perspective, brands have the duty to educate by supplying objective, correct, easy to understand and unambiguous information." (*Int. 3*)

However, in many cases it is difficult for brands to effectively transmit this understanding, thus there shall be the additional backup of neutral stakeholders and other supply chain actors. Candiani describes the stumbling block of having only one type of interlocutor: "We have taken active roles in raising consciousness towards brands that can then educate consumers, but now we're also trying to get directly to the consumers specifically for what regards the use phase issues of the specific fabrics." (*Int. 5*). Consistently, this shall include washing and caring knowledge, end of life alternatives management and repair service requirements. According to the Fibersort Interreg NWE project: "There also needs to be increased citizen awareness and education for the disposal because it is very often for sorters to find a lot of household waste in textile bins. Additionally, for instance it has been suggested that it is better to throw the clothes in a bag because at least in the Netherlands the containers have let water and else inside." (*Int. 4*). On the other side, since the repair service is costly and the related transportation unsustainable, MUD Jeans encourages to repair locally, so that also more tailors are able to get jobs" (*Int. 7*).

The whole process of education may be further guided through codes of reference, to which the consumer can relate and rely on, in the form of eco-labels.

2.10 ***Environmental certifications***

According to Orange Fiber: "The process of certification is fundamental, now even more than 2-3 years ago. At that time, it was enough to say that our product derived from an alternative raw material. Today this is not sufficient anymore: when fashion brands approach us they always demand if the fabric has diverse certifications." (*Int. 2*). Also Chemical Recycler X is encountering these requirements: "We're considering various certification options to implement in our licensing package. We have been granted for Cradle-to-Cradle certification. Which one will be the most important is still undefined but truth is that they are becoming critical. B-corp is surely very interesting and the Higg-Index was already requested by some investors." (*Int. 12*). Similarly the large incumbent of Lenzing states: "Regarding environmental certifications, I think they will be very important, maybe even 8 to 9 over 10. For our recycled products we have the RCS and we're currently applying for the Global Recycling Standard. Anyway we see a lot of increase in eco-labels and in people that want to earn money but then the landscape gets too broad and uncontrollable. Some of them which are very big are also starting to get very harsh restrictions or they even lose a little bit of their basis. (*Int. 1*).

In these regards, EVRNU explains how for instance B corp "does open some doors for networking but entails also great time and costs for the certification process. Thus also in the US eco-labels are still debated a lot, even though they ever more become a necessity (*Int. 11*). Luxury brand X adds that the problem often lies in a not valuable certification process (*Int. 8*).

An improvement in accuracy, manageability and controllability may be found through the exploitation of digitalization and stricter regulative requirements.

2.11 *EPR debate*

Being a value and incentive redistribution regulation, EPR implies the potential to drive a widespread standardization and transition towards other more accurate and sustainable business objectives. Among interviewees there is generally a favourable consensus, even though some actors will benefit more and others will need to revolutionize some business aspects in order not to be weakened in competition. Still, all actors also see wide implementation and management stumbling blocks that may hamper the effectiveness of such a fiscal system.

Candiani, for instance, states: "Regarding EPR, I personally think it's a positive thing. For sure there needs to be the presence of governments and policy makers to enable it to happen and also provide financial support. I do think they need to be very active. A great part of the environmental impact weight is on our shoulders because for example brands benefit from our sustainable investments but often don't want to pay 50 cents more, not always. Surely there is a handful of brands that are very committed, but I still feel that as a supplier we get squeezed by both ends. On a personal level I agree that the companies should be the responsible ones for what they put out in the environment/market" (*Int. 5*). In this sense EPR may also support the levelling of traditionally asymmetric supply chain players' relationships and the clarity and fluency in the process of finding the best partners for each innovation project or material supply. Orange Fiber confirms: "Our clearly deductible opinion is that surely we agree with any strategies which favour the complete closing of the fashion loop and accordingly in our commercial relationships and relationships we privilege those companies or individuals which are taking an absolute care of sustainability matters and which work, operate and project within a circular economy perspective." (*Int. 2*). Similarly, Renewcell affirms: "Regarding EPR, we're certainly interested in getting more waste separately sorted available for us to process but we don't have a really firm position on which exact scheme would be the best way to do it, if it's EPR or some kind of

tax, regarding how much recycled materials you have in your products. Any policy prescription that pushes the industry towards more recycled materials and more circularity is good" (*Int. 13*).

In this environment of positive but uncertain perceptions, the Circle Economy addresses the need to complement diverse incentive actions and approaches in order to reach more concrete results according to where top-down efforts and resources are dedicated. This relates to the ineffectiveness of finding a single optimal pigouvian tax (Massarutto, 2014) and to the efficacy of using complementary instruments when the policy has to address multiple market failures and transactions costs are relevant (Walls and Palmer, 2001; Lehman, 2012). Specifically: "On EPR, we do advocate for that being implemented at national level, but we also do believe that this scheme will support the infrastructure for collectors and sorters, so you need it but only with extended producer responsibility you will not incentivise the whole value chain. Basically, you need to have a way of ensuring that the basic infrastructure is out there and is feasible economically to sustain, but then you need to balance it out with reuse and recycling targets and incentives for green public procurement." (*Int. 14*). In these regards, VF points out the need to regulate both the role of common end-of-life management infrastructure and on the other side of single companies as circularity promoters and actuators: "EPR is a legislative model, thus as VF we're working with the whole industry to advance solutions, also because the European Commission is developing the 2021 Action Plan for a textile circular economy, which will include EPR logics. We support all this work and offer our insights because the regulative body normally doesn't have technical knowledge of which may be the barriers and operational hurdles. Different story are take-back programs because even with an Extended Producer Responsibility scheme if you carry out products recovery you're not exempted from paying the fee." (*Int. 6*).

In this respect there are many other organisations, as also Confindustria in Italy, which are interested in the enlargement of reverse logistics processes. However, according to Rete ONU, these activities may drive the "transformation of points of sale into sites of take-back followed by disposal, since there are still no standardised and precise definitions and sometimes energy recovery may be included within the concept of 'reuse'. Thus there is the risk to let the control of supply chains in the hand of organisations with interests opposite to garment recovery, since reuse may contend markets slices with their offer of new production items." (Rete ONU) In general, it seems to depend a lot on the type of organisation and type of customers it attracts. Hence, "the task of brands is to deploy a design compatible with reusability and recyclability, aside from financing a super parties organisation which can then redistribute to recovery operators. Eventually, once eco-design will be effective also the reverse supply chain will become more sustainable and the producers' contributions shall be reduced." (*Int. 9*).

Accordingly, EVRNU states: "If you can start putting responsibility on producer/designers, pushing them towards more eco-design through less printing or only water based dyes, or through the exploitation of energy efficiency logics, it will be then possible to widely increase the value of the discarder item." (*Int. 11*).

In these regards, the effects of concrete EPR schemes shall be analysed more in depth in order to find strength points and improvement gaps. The Chemical Recycler X interviewee articulates: "In my perspective, EPR will be fundamental. We're very happy for how it works in France and how the taxation is used for innovations. We believe it may truly push an acceleration in the transition. For sure, brands need to educate consumers towards less consumption and more reuse. Then our technology would complement these efforts for what regards everything that is not possible to reuse." (*Int. 12*). In particular, "the French EcoTLC scheme is approved by the recoevery and second hand oeprators especially for the governance scheme. Still, it shall be improved on the side of the incentives because they are granted only to sorting plants and not to single collectors, enhancing the possibility that small players of recollection may become hostages of the market" (*Int. 9*). Furthermore, VF specifies: "the French EPR model has some limitations, for instance, in regards to the guidelines for product categories, which include t-shirt, pullovers, jeans and so on but then there is great slice of items which are excluded, thus it is necessary to find more accurate and applicable guidelines. On the other side, we're also pushing a lot the consideration of the multifarious shades that lie between an outdoor sector which aims at high performances and a casual wear sector. This is because if I have to design a product that is required to perform at -30/50 °C, where in some cases it is a question of survival, I cannot use a defined percentage of recycled inputs because they don't supply the same levels of insulation or duration. Obviously the matter is completely different for an item which will be used in the city of Milan, thus needing much less research and development." (*Int. 6*).

Generally, it will be necessary to accurately design each detail of the evaluation and assignments of incentives in order to facilitate true sustainability champions, that shall then have the power to influence also innovation laggards of the industry.

Specifically, "from the industry point of view it will be critical to work on fiscal discounts. Whether VAT discounts or other types of incentives, they need to be there because the companies that are investing in specific technologies and diverse design techniques bear high costs which alternatively would be transferred to the consumer. The discount on VAT is particularly interesting and desirable, because otherwise determinate investments become unfeasible for what regards the loss of competitiveness." (*Int. 6*).

Finally, limits are found in relation to the applicability of EPR schemes in a such diffusely based industry. Lenzing states: "For the extended producer

responsibility, I'm neither pro nor con, I would say I'm both also as company: on the one hand, it is a very important step because you cannot put all the responsibility to consumers because we see how this ends (we see already some interesting examples from the electronics industry with a lot of projects that had to be started in third world countries because of all the electronic wastes going there). I think if we really build up EPR systems we need to take this into account, we need to consider that this is something that has to be based on the global scale: because otherwise we tend to shift the problem and also because the textile market is extremely globalized." (*Int. 1*). Likewise, also Brugnoli points out the related complexity: "According to us it is difficult to realize, due to the complexity of the global distribution of manufacturers and distributors and due to the diverse regulation systems present in each nation." (*Int. 3*).

In these regards, only convenient and still effective instruments, as digitalisation technologies may provide the required solutions.

2.12 *Blockchain solutions*

"Block chain will be a great opportunity for fashion for sure because of the necessary advanced traceability." (*Int. 5*). This interview citation already suggests the intensity of the interest in the potential that such a revolutionising technology bears for solving supply chain related issues, even though there is still a lot of uncertainty on the market. Chemical Recycler X states: "We have positive perceptions in regards to block chain but we still miss clear strategic ideas. We perfectly know that traceability is fundamental: we need it in order to assess information on our incoming feedstock. Again we will be manufacturers of a product, thus if it may be possible to trace it along the whole supply chain then finally returning to us, this technology would be of paramount importance." (*Int. 12*). Similarly also Orange Fiber is planning on it: "We're already in contact with companies specialized in delivering this service to innovative enterprises as ours, since traceability is ever more demanded by clients. So at present we do not use any of these methods but we will as soon as with the new production for this summer." (*Int. 2*).

Nevertheless, Lenzing underlines the barriers and the complexity present for its implementation in the fashion industry: "For us block chain technology is looking forwards to transparency, traceability and making this data accessible to brands and consumers in a digitized way and this will help in forcing standardization of manual data input-output, so also enhancing a lot efficiency, which I think is the greatest driver. Next there is probably the security provided through encryption, but on the other side this might also be the biggest issue.

One barrier is the fact that the whole real application is asked by consumers (demanding transparency) but it strongly depends on the brands. On the other hand, the technology is itself a barrier in the sense that you need a lot of processing capacity and if you start with the whole textile value chain which is very broad, since you have a lot of small players, it might possible that you need too much processing capacity (I think there were already similar examples in cacao production), so it is not always possible." (*Int. 1*). Similarly, VF further unfolds: "Block chain is a concept and a technology which we're investigating, it is very interesting, yet we collide against the complexity of the textile supply chain. Usually we consider 4 tiers of suppliers, where tier 1 for us is the supplier of the finished garment; but in some cases we reach tier 7 or 8, just for all the diverse steps and transfers present in this value chain. Many times specific raw material supplier may not even have access to the internet connection or to a computer. Thus the concept needs to be adapted to the manifold realities and at the moment it is still very tough to implement it along the whole supply chain. We're trying to develop it in particular scopes – as in the Napapijri line for instance where wool is traced throughout a blockchain technology. We also create our 'Source Maps' to trace all production steps also basing on the integration with other traceability systems usually in the form of environmental certifications as the Responsible Down Standard which ensures a transparency over all steps of the materials. Evidently many of these measures are still done in excel files, given also the vastness of our supply network with an estimation of 6 million workers and many thousands of suppliers at tier 1 and 2. It comes without saying that it will be a step by step approach." (*Int. 6*). Finally, also Candiani merges different types of traceability instruments: "Regarding our circular initiatives, we focus mostly on our sourcing and we do have a block chain pilot project that we're developing (so still nothing formalized) looking at a specific stream of cotton coming from Brazil. The other type of more informal traceability that we have exists thanks to the fairly close relationships with the majority of our suppliers, so that we have a kind of oversight on where our things come from, in addition to co-creating certain materials, whether it's a dye or a certain fibre or elastane." (*Int. 5*).

Hence, in general at the beginning phase block chain may play a critical role in supporting other traceability systems. Lenzing widely employs diverse methods of fabric certification since it is also a branding service, done on mostly finished yarns – i.e. specifying who span the yarn, which kind of yarn it is and which product they are going to be used for. Furthermore, they balance this through checking with direct customers and fibre identification systems, where the production process undergoes a chemical alteration in order to understand if it is really their fibres (currently done for now for 2 fibre types). Regarding these incorporation technologies, they refer to doped materials. In addition, the block chain pilot will be used to further check their fibres, for online monitoring of production and for data analytics, even though it is still in nascent phase. (*Int. 1*). In respect to physical technologies for the

upload of data into the digital layer, there is a lot of liveliness in the research and development of alternative solutions to RFID, which may follow the specific material along the whole closed loop. Thus, also VF confirms: "Genetic markets are something that we're investigating as well. They are extremely interesting because they would allow to have a clear view over the sources of the garments, especially in a full circularity perspective. This becomes critical in the moment the item is returned to get recycled: here hurdles may lie in counterfeit goods or in the presence of chemical products used during production. All these transparency instruments thus ease the complete tracing of a garment, explicating where it was manufactured, which were the transfers and how the recycling process may be safer. At diffused operational level we still didn't implement anything but it is a recurrent topic: there are indeed cost-garment relations which may become significant but it is always a question of implementation feasibility." (*Int. 6*)

Finding a way through these practical hurdles and having an extreme accuracy in data generation may actually also ease the feasibility of other systems. In particular, Candiani points out: "the importance of green certifications lately also pushed a boost in their number, leading to an obscure market of organisations falsely trying to make profit giving certifications without actually accurately controlling. Thus in this field block chain may bring benefit to the truly sustainable and accurate certifications through the full traceability of flows and processes." (*Int. 5).*

Blockchain - Business example

How was the pilot project born and developed?

It is still under development but basically it was born because there is a lot of complexity in the cotton supply chain. Mostly you can trace cotton till the ginner, so the processing stage after the field level, but it's quite difficult to trace it back to the farm level so this is the reason for the emphasis on the project. Moreover, it is BCI cotton but one of the weaknesses of this certification is that they work on this mass balance system so it's not really about traceability, not as it is with organic. A lot of people are skeptical of BCI as a sustainability standard because of this lack of transparency. The cotton that gets into our warehouse might not even be BCI at all because it has been mixed in this whole mass balance. Furthermore, there are questions about the effects on the ground, so if it's having an impact, and then the problem is that there is no way to measure it, because you don't actually know where it comes from.

Thence, the project did require that we partner with a number of actors, so one of our key cotton traders is involved, with whom we worked for a long time and we trust, who has literally eyes and feet on the ground and is in touch with farmers, understanding the situation there. Generally, we identified only partners that would be suitable for this project and particularly the farmer is close

to the ginner, so we have a direct link which helped a lot in the progress of the project and also made that part of the supply chain clear and well defined. From the top-down approach, our CEO found a provider (Product DNA, based in Switzerland) of this software and system to specifically trace the supply chain and make it visual. He chose them as technological partner in order to develop the more technical aspects of the supply chain exactly for this project. The idea is that we'll start with one batch of cotton but then we want to expand this to all of our products eventually.

Since it will applied to your own suppliers, did you choose a private block chain design?

No actually we will have an interface, so the larger idea is that it will be something that we can provide to brands. It is a traceability instrument but also a platform that they can use and then ultimately all their customers will be able to use this as well. Hence it will be a hybrid maintaining access on the downstream and some privacy levels on the upstream.

Regarding the physical technologies that enable tracing, do you use RFID or else?

For the time being, we've been doing it all more or less through documentation added manually, so there is still no last generation tracing technology. Anyway that is something that will be discussed in the next phases, thus deciding either to use genetic markers or RFID, finding out that will look for the end consumer. The other thing is that it becomes a bit complicated, not from the genetic perspective, but because for example for the RFID tag also the brand would have to be involved, since the tag should then be in the garment, so it shall be discussed with them.

Regarding the informatics infrastructure, do you see limitations for the implementation in developing countries?

I think it is a matter of having trusted partners and maybe as volumes increase they may create a problem. It will have to be something that is available in developing countries as well, so also for people that don't have the digital infrastructure already in place. Anyway I know there has been also some projects on easy to be used systems, but probably requiring the genetic markers that would be in the cotton itself so that farmers could just scan and then everything would go automatically. Such solutions will be particularly relevant in India where there are so many little farmers and ginners and where then everything gets mixed at one point, thus addressing that kind of supply chain complexity.

Regarding the data that you trace now, what are in general the classes of data that you save on the blocks? Are you using a standard structure that the technology provider offers or is it your internal structure of data?

Yes, the provider is giving us a structure to work with. In terms of the data, I think the goal is to trace every stage of the supply chain so from the farm, to the ginner, to in-house. Then will be looking through every part of the supply chain at the impacts in terms of inputs, of water and chemicals. I'm not sure if we've attached already also air emissions. It does bring up for me though the need for that kind of data. We're not taking into consideration transportation at the moment, also because it is not something that we generally think of in the scope of our business, also because here in house we don't have and don't deal a lot with transportation at least internally. We're still trying to define what to share and what should be put on the block chain.

The other barrier that comes up is the idea of intellectual property rights and privacy issues, so how to work around that. I do think that the technology is really promising in itself but then how to realize it for a complex supply chain as fashion is a different story. I also don't know when all those pilot projects popping up are going to be unified in a single block chain, which would be the ideal or least having all diverse block chains interacting. So connectivity is the next challenge that will have to be remedied.

What do you use this data for?

The main thing is definitely the transparency and traceability, thus being able to share this information with our clients, with the brands that we work with. There is definitely also an interest in having environmental data, so understanding the impacts of a certain fabric throughout the supply chain so then to create a baseline to understand impacts of decision making in real time.

Do you foresee that this enhanced transparency will also enhance the collaboration along your value chain or maybe even raise the potential for easier funding and certifications?

Collaboration I could see more so, thanks to knowing exactly who you work with in the supply chain or who is out there. Then you can also have more of a record. So for us it works organically and most of our partnerships with suppliers have been long-lasting but I could see it for other companies being something significant since if you start identifying partner that could work better for you, then you have this digital record to check. I don't think it going to be the first benefit of the technology but collaboration could be still something relevant to exploit.

Regarding certification, I think it could make the process easier, so reducing the administrative burden of certification but that is something that would have to be generated and included by the certifications itself, identifying their guidelines for how this information is input into the block chain and how it's communicated, thus identifying the indexes they'd want included etc etc. I do think it could make it easier for that reason.

Regarding funding, I could see that for sure as well because transparency is a mean for risk reduction. So if you know what is happening in your supply chain and you can show it in an authentic way, that cannot be tampered with, I do think it's something that would be appealing to investors.

Do you see it possible that also policymakers could have a role inside the block chain, tracking the volumes and performances of the producers, in order to understand exactly what firms shall be paying more by being polluters and which ones shall be subsidized for their sustainability efforts?

I absolutely think it has the potential to do that but again you would have to have all the actors participating, which would be the only issue. I believe it could be a robust way to track performances but for the comparability of it and usability for policymakers it will be required that everyone utilizes it. Furthermore, it shall be required to have a functioning block chain everyone agreed on. For the reverse logistics part there for sure will need to be the implementation of RFID tags or similar, so that will be the more critical part in order to close the loop. If it becomes the norm that goods are being brought back into the system, then for sure it will be in the interest of policymakers to also support brands or the private sector in general to be enabled to do this.

In conclusion, it is possible to remark how the state of practice widely reflects the state of the art presented in the previous section but also provides additional insights about which technologies and impact areas show the greatest resolution potential and about the economic unsustainability of socially and environmentally sustainable companies.

First of all, the degree of complexity of making the reverse supply chain function properly is determined by the fact that secondary closed-loop markets for recovery and recycling need to be almost completely build up from the ground. As evident, there are already manifold organisation interested in the growth in this fields. These pioneers are seeing possible valuable profitability gains but they are striving squeezed between financial burden of investments and low consumer understanding as well as responses. Thus this aspect raises the prerequisite to start from the strategic development of actions to enhance consciousness among the majority of consumers.

In these regards and also aiming at fluid, transparent and worthy supply chain relations, green certifications represent a form of signalling. As a matter of fact, one large complication lies in the issue of hidden information which produces a 'market for lemons' situation. If quality cannot be verified, a buyer will be instinctively willing to pay the value expected on the market, which will be an average and will likely throw out of the market those firms bearing higher costs for an overall beneficial purpose and investing in higher quality and technology. Basically, this is what happens in the market of recycled fibres prejudiced as of lower performances through generalisation. Likewise, innovative companies proposing valuable business models oriented towards prevention and reuse usually receive unfavourable conditions when searching financing for innovations, because external capital providers do not understand the quality of the project, in an asymmetric information configuration.

In order to solve these market failures, the intervention of public authorities is fundamental. The stimulation for certification, product eco-labels and reputable industry alliances, spurring supply chain collaboration, represent a remedy against asymmetric information. Facing clearer market conditions, consumer behaviours would be more easily driven towards a preferable balance of consumption and production. Furthermore, the achievement of this desirable market equilibrium may be accelerated and granted by a correct regulative framework of incentives towards economic agents' actions. In this respect, interviews unfold the fact that EPR alone difficulty incentivises the advantageous following of the waste hierarchy. There would be heavy rebound effects because, with an effective and efficient recovery system, the industry would be entitled to throw away greater amounts of waste. In addition, EPR systems need to progress for the sake of attaining tangible effects on the industry and would thus need to differentiate much more thoroughly and

individualise the application cases. Hence, as the Circle Economy stated: “You need to have a way of ensuring that the basic infrastructure is out there and is feasible economically to sustain, but then you need to balance it out with reuse and recycling targets and incentives for green public procurement”. In connection with this, aiming at the propelling of the whole closed-loop infrastructure, brands play a crucial role, by impacting both upstream and downstream and having an extremely strong bargaining power.

Finally, interviews demonstrate wide consensus on the potential of blockchain in solving a wide majority of fashion industry current state issues but also foresee various implementation stumbling blocks. The evolution of this digital layer will thus demand to be complemented with other basic technological support especially in developing countries, which represent the major playground of fashion supply chain actors. The desired scheme of redistribution of value, incentives and fees according to a polluter-pays-principle will thus need to be designed accurately implementing also the technological perspective.

Section 3

BC-PS FRAMEWORK DEFINITION

The evolution of the proposal of a blockchain (BC) - enhanced Product Stewardship (PS) framework for the fashion value chain roots in the discerning analysis of existing paradigms and experiments retrieved from the state of art and practice.

The structure of this section will thus be subdivided in two. The former part will highlight and synthesise the operational and systemic hurdles the research aims at puzzling out, in connection to the innovativeness level of the comprised concepts as well as to the conclusions and correlations found among diverse theories. The latter part will embody the concrete aggregation process of the building blocks making up the final novel framework. It goes without saying that the true resolution potential will be embraced only when all fragments will be aggregated, outlining beneficial links and synergies.

3.1. CONSIDERATIONS FROM STATE OF THE ART AND PRACTICE

In respect to the literature gaps found, the displayed fashion ecosystem is apparently characterised by multiple stumbling blocks which are widely highlighted also during the interviews. The first crucial step for the development of the model will thus be to unravel which hurdles are possible to be solved through the integration of circular, regulative and digital innovations.

3.1.1. *Proposed issues to solve*

As discussed in the previous chapters, fashion industry systems mirror an unsustainable perversion in consumption as well as production patterns and are unlikely to solve current state issues on their own. Circular economy, polluter-pays regulations and digitalization all have in common the comprised potential to minimize environmental impacts across the whole supply chain, while also maintaining or even enhancing the economic competitiveness of companies. Still, taken individually they are characterized by limitations in the effective accomplishment of improvements for a broad number of impact categories. It is therefore beneficial to assume a more integrative and holistic perspective (Todeschini *et al.*, 2017), in order to accurately study which modelling, regulative or technological feature best drives the systemic transition. For instance, the implementation of CE strategies requires new organizational and logistics models, industrial process and product innovations, as well as a redefinition of the business paradigm (European Environment Agency, 2016). Specifically, all these changes will have to be economically, socially and environmentally sustainable in order to guarantee a successful implementation. This confirms a strong need for further research about more effective CE strategies evaluation, particularly on the micro level (Elia, Gnoni and Tornese, 2017). Each of the proposed valuable models leaves indeed wide peculiar improvement gaps that may be filled through a consolidated value redistribution framework.

First of all, an apparel and footwear specific pitfall relates to the scarce organic economic viability of end-of-life management infrastructures. The squeezing unbalance present between declining reusable fractions of recollected goods, in relation to the decrease in fibre and garment quality as well as increase in psychological disposability of items, against rising collection, recycling, disposal and fiscal costs, challenges indeed the persistence of collectors and recyclers but most of all sorters. In addition, the economic sustainability of current second hand business models is further undermined by the fact that high income countries offer a great supply of used garments but demand is low thus driving down prices, whereas in low income countries happens the opposite. The synchronization of excess supply and demand will thus be crucial to drive value accretion and avoidance of burden shifting problems. Lastly the stagnation of overall reverse value chains lies in the inexistence of pertinent refurbishing markets, urging the prerequisite to expand markets for innovative sorting and recycling technologies, in order to stabilize economic and logistical conditions. This shall enable a greater clarity and understanding of profitability gains potential, driving further growth and activation of value loops.

Accordingly, a second massive stumbling block is the perseverance of widespread uncertainty feelings across stakeholders. This aspect particularly

relates to the complex industry structure as well as blurry, asymmetrical and often untrustworthy supply network relationships. In addition, supply chain collaboration is heavily weakened. There is a high subjectivity upon the firms involved in each connection and the power is systemically held by giant players in retail and fibre production stages, forcing a general incentive misalignment problem and an inability of "sandwich spectators" (Franco, 2017) in the middle of the value chain to carry out investments and innovation projects. Beyond these systemic hurdles, there is also the fact that current recycling technologies seem to function properly only for viscose-like fibres. All other recycling as well as sorting technologies will still require 3 to 6 years for the technical improvement and scaling up of processes, thus further increasing the hesitation of widespread revolutions initiatives.

Policymakers and third-party organizations shall thus take an active part in designing the system in order to ease the individual firm-level initiatives and support supply chain collaboration. A limitation that characterises current Extended Producer Responsibility examples, as the French case, is in fact the inability to correctly and effectively incentivise a diffused transition towards sustainable production and commercialisation behaviours, partly in relation to the low differentiation within product categories and distinct firms' fee level. Generally, it is widely acknowledged that it will be advantageous to incentivize individual companies' innovations, especially brands, because they may give rise to the chain reaction and the pull other SC partners responses.

3.1.2. ***Novelty of the topics***

Essentially, besides the relative freshness of single topics, the actual novelty of the approach stays in the integration of the three different paradigms' strength points to solve each other's weaknesses in a synergetic approach.

In particular, product stewardship principles support closed-loop models adoption by reducing investments uncertainty; solving financial burdens, especially for hard-tech innovations; stimulating a regular demand; enhancing consumer consciousness; providing an optimized reverse supply chain infrastructure; financing the expansion of recycling markets. On the other hand, circularity principles support extended producer responsibility frameworks by easing the achievement of waste minimization targets as well as propelling a higher economic competitiveness and thus more accurate incentives to participating firms. Finally, blockchain architecture works on

both sides as an enabler, since it intrinsically raises extensive traceability. On the circularity side, it facilitates reuse and recycling processes, in particular favours rental and loyalty programs effectiveness, thus supporting servitization developments. Furthermore, it fits customer-centred design through the extraction of marketing insights from data collected, while also reinforcing certification processes and eco-labels. On the EPR side, it permits a more precise definition of responsibilities, it drives a transparent apportionment of fees which may reflect more accurately true net management costs, ensures transparency, eases surveillance, reduces free-riding possibilities and enables a fluid assignment of take-back rewards for consumers as also fees and discounts for companies. Inversely, an effective product stewardship configuration, solves blockchain issues related to regulatory uncertainty and perceived legal risk, providing participants incentives to perform best standard practices, providing incentives to each supply chain partner for agreement to board onto the network.

The differentiation factor thus lies in merging these multi-field innovations at a meso-economic level of analysis, figuring out stakeholders' interactions asymmetries, supply chain inefficiencies and systemic barriers against sustainable change.

3.1.3. Theoretical takeaways to harness

This business modelling, regulative and technological association legitimates the drawing of further conclusions, reached through logical reasoning, intersection and systematization under a common perspective of present literature's critical analysis considerations. These conclusions will subsequently stand for the principle assumptions laying the foundation of the framework to be developed.

A first restraining issue against the establishment of value circulation, stays in the inexistence or rawness of reverse supply chain infrastructures, causing severe systemic inefficiencies and a curbed progress of sorting and recycling technologies. Consistently, the reasons for a currently prevailing low quality and high price for recycled materials refer to:

- High investments for recycling technologies with no certainty, since past examples did not guarantee required performances of recycled fibre (shorter yarns, more difficult to be spun…)

- Misalignment between relative demand and supply, due to variability in quantity and quality)
- Insufficient volumes of production to reach economies of scale
- Low credibility because of missing proof of definite higher sustainable

The critical mechanism to study and evolve is thus how closed-loop textile management's economical sustainability may enhance the flows of recycled and reused resources, thus enhancing the environmental sustainability. The underlying logic comprises the following reaction chain: incentivising the end-of-life infrastructures, drives an optimisation of the whole reverse supply chain, which in turn permits an effective value flow across multiple sequential loops, finally the market expansion of circular materials grants excess profitability which attracts more EOL players, which then trigger further efficiency of the system. Basically, by changing the percentages of volumes for each resource or waste stream, also the related prices shall change and therefore the environmental performance shall rise accordingly.

Hence, as in a complete circle, everything seems connected. For instance, with any probability, the fee bore by distribution companies will be directly transferred to customers within the final price, following an instinctive and business logical rationale. Eventually, this will lead to a loss of convenience in unsustainable options, thus predominantly and effectively pulling a change in competition patterns, since sustainable companies' products will increase in competitiveness on the market, achieving a related boost in revenues. Moreover, additional declines in operational costs will be included in the implementation of improved product deletion choices. Indeed, block chain technology activates and upgrades the inter- and intra-organizational information management systems that facilitate product deletion decision making and advances circular economy development and operations. Consistently, product deletion may become, in the short-term, profitable not only from more rationalized product portfolio management, but also from the utilization of freed up resources and materials as closed-loop inputs (Kouhizadeh, Sarkis and Zhu, 2019).

In second place, the fragmentation aspect of the supply chain shall be deepened. As stated above, current business relationships are widely asymmetric, basing on the impact of the supply chain position of a firm as well as on the relative size or power of the innovative firm versus the relative size of its supply chain partners, since it greatly determines the latter's willingness to engage and invest in the joint innovation effort. This pulls the basic requirement for fostering collaboration and redistribution of incentives. Ultimately, this fragmented and fundamentally transactional setup has fostered an environment that is not conducive to investing in R&D and innovation projects. While brands make commitments to undertake more sustainable practices, much of the change must occur at different stages of a highly fragmented

supply chain. Consequence: players in the supply chain are often asked to bear the risk, costs, and effort of innovating, with little guarantee that they will be in a position to capitalize on their investment. The ultimate beneficiaries of innovation are the brands, which reap the rewards of marketing and offering differentiated products to end consumers. As a result, suppliers and manufacturers positioned earlier in the SC have little incentive to support and use these disruptive technologies, unless companies in subsequent stages of the supply chain are willing to pay more than a marginal surcharge for innovative products. The lack of long-term, trusted relationships further fuels opacity and misaligned incentives, and limits the industry's opportunities to maximize the overall impact and network gain that innovation could bring to all parties along the value chain. (Fashion for Good and Boston Consulting Group, 2020)

In respect to this, blockchain may once more represent the effectual panacea sought-after. The enhanced levels of trust embedded let in fact the potential for strategic, long-term relationships grow in a diffused manner. As a logical consequence, this may result in a greater level of innovation speed and disruptiveness, as well as an overall optimization of flows thanks to risen supply chain integration. Moreover, the secure traceability characterizing blockchain architecture also helps small firms and start-ups to obtain financing and certifications, thus expanding even more innovation potential, through the collaboration of such disruptive minor realities with powerful incumbents. Consistently, the change in competitive patterns shall also be spurred by the fact that sustainable companies will want to work together, leaving behind unsustainable ones, because together they may achieve much more and so gain higher discounts.

Another crucial future feature relates to the trend in servitization and expanded sale of performance in order to achieve long-term sustainability. In these regards, the most beneficial relation is found between blockchain technology and rental business models. The extensive traceability will provide a great amount of data to mine and value to extract. Information about garments' usage and conditions, production inputs and processes, as well as consumer preference may indeed be exploited to adapt the commercial offer and improve margins. Furthermore, renting options also intrinsically incentivise a design for higher quality and life-expectancy, granting waste prevention principles' fulfilment and overall pollution reduction. The criticality comprised is about the fact that this business model is profitable mostly for luxury and high-end brands. On the other side, low value companies shall position in the second-hand market targeting cost-conscious consumers.

Finally, the general conclusion refers to the need to develop a differentiated model in which to accurately evaluate the best economic and environmental fit of each business model for each type of consumer and company objectives.

3.2. FRAMEWORK DEVELOPMENT

Given the current state complications and limitations, a novel proposal shall answer to designated research questions and build a theoretical substratum for further technical research and development. As anticipated the framework will act on three distinctly suggested conceptions for the final advancement of the fashion system sustainability performances, referring to Circular Economy, Digitalisation and Product Stewardship. The next chapters will thus move through the prerequisite 'Business modelling diversification' (See **Section 3.2.2.**), the 'Product stewardship substratum' (See **Section 3.2.3**.) and finally 'Blockchain: the enabler' (See **Section 3.2.4**.). The first of these chapters will lay the basis of the fundamental prioritisation among proposed sustainability- and circularity-oriented short term tactics and long term strategies of fashion industry players, according to waste hierarchy principles. The second chapter will unfold the instrument exploited for the realisation of this priority order, i.e. a diversified scheme for the redistribution of value, through subsidies and taxes allocation across the textile supply chain, aiming to concretise effective incentives for operating businesses. Consequently, the third of these chapters will display the potential of blockchain architecture in overcoming product stewardship stumbling blocks, by providing advanced traceability of flows, payments and consumer preferences.

Accordingly, these three chapters will represent the three main building blocks of the novel framework, as shown in figure x. Finally, **Section 3.2.5**. will provide the comprehensive outlook of the integration of these building blocks in a consistent model.

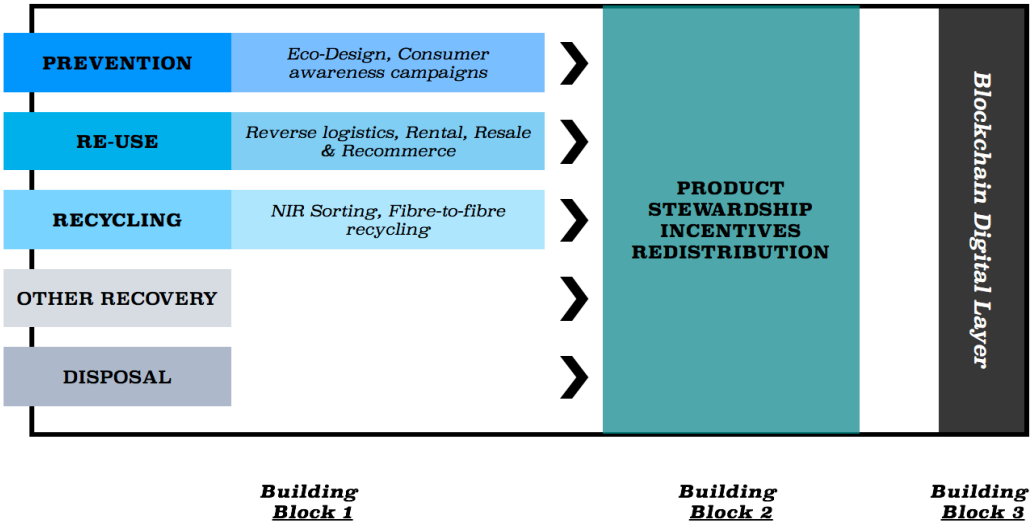


Figure. 30 - Framework building blocks

3.2.1. *Framework goals and principles*

According to the methodology exposed previously, the insights from state of the art and state of practice have been reiteratively analysed and integrated in order to find the most fitting resolution proposition to fill the literary gaps found and to support the facilitation of sustainability champions well-aimed advancement, parading for the overall widespread transition of the industry. Once again, the objective of the dissertation will thus be to:

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Establish a link between regulative policies and technologies exploitation, in order to develop a framework characterised by well-aimed adaptation to the business context, concrete implementation potential, incentives effectiveness and ability to drive widespread balanced consequences throughout the whole fashion value chain.

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In these regards, it is fundamental to underline that, in order to gain full effectiveness, it will be necessary to move forward on the time dimension. The framework will indeed make use of technologies that are forecasted to be at full scale and achieve required performances in the years. Basically, the proposal thus serves as a preparation method in order to fuel the development towards the aspired objectives and in order to be completely ready to exploit these revolutionising technologies once they will become diffusely available on the market. As a matter of fact, on its own this technological substratum may likewise fail on bringing broad sustainability improvement effects if note accurately supported by a complementary surrounding infrastructure.

Aiming at the realisation of the full potential of sustainability performances improvement entailed in these technologies, the paramount guiding principles will be the "Polluter Pays" (PPP) and general economic convenience. In regards to the latter, the underlying assumption considers price and costs as integral and predominant decision drivers in the organisation of all apparel ecosystem activities, even though other more qualitative keys may have an extensive weight. Economic viability with thus need to be always the baseline on which to add over additional complementary performances deliberations. In particular, within the textile and clothing environment, this favours the preference for closed-loop systems, which keep commercial value high even in multiple consequential life cycles, against open-loop cross-industrial options that knock down potential circular profits. Economic value is thus the key for activating reverse supply chain evolution and triggering widespread behavioural transitions. Once this condition is assured and aligned with specific players' requirements, the redistribution of responsibilities, costs and benefits

shall take place in order to erode the convenience attainable through unsustainable production and consumption choices. PPP is defined as the allocation "of costs of pollution prevention and control measures to encourage rational use of scarce environmental resources and to avoid distortions in international trade and investment" (European Commission, 2012). The imposition of taxes shall thus help to uncover the negative externalities present and make economic players aware of the consequences they produce with their sightless actions, driving managerial behaviours towards clearer choices for the short term as also more importantly long term persistence.

Among the correlated principles there will thus be a crucial search for resource efficiency and a compelling need to revolutionize traditional competition logics completely. The sale of performance will become a structural pillar in a world where worth is increasingly extracted, exchanged and redesigned.

Similarly, the novel framework shall be characterized by an ideal of neutrality aiming to fully constitute a solid base for the foreseen development. The top-down approach shall be designed to function almost automatically, reducing intermediaries and facilitating fluid transactions. Blockchain will thus gain prominence establishing a lean and digital mechanism in order to trace flows, activate smart contracts, enhance a checking system also through certifications. Above all a centralised control organisation shall work solely on the continuous functioning of the implemented system.

Under these directional conditions, the model shall be further build up and tailored following these general objectives:

- *Effectively apply the waste hierarchy to the fashion supply chain*
- *Individualize taxes & subsidies*
- *Solve inefficiencies of EOL infrastructure*
- *Favour sustainable innovation and supply chain integration*
- *Share net costs and benefits of optimised reverse supply chain*
- *Minimize uncertainty*
- *Create win-win conditions among traditional direct value chain actors and reverse value chain actors*
- *Empower customers thanks to information availability*
- *Reduce used clothing exports to developing countries*
- *Improve certification process through BC*
- *Minimize collective action problems (interplay of different actors and stakeholders)*

Given the extensive field of application as well as the variety of business models and products to embrace and plug in, the framework should comply an integrative, clear and precise scheme. Consistently, as anticipated, its illustration will thus follow three different topic sections, adding one building block on the other.

3.2.2. *Business modelling diversification*

As already stated above, referring to the numerous market failures to contrast, no single instrument, not even an optimal tax that accounts for all externalities (what economists define as a "pigouvian tax"), can deliver optimal results (Massarutto, 2014). It will be demanded to structure a coherent and well-aimed set of measures and business modelling incentives, merging the regulative theory and managerial practice considerations.

In particular, the BC-PS framework will subdivide the different measures according to the European waste hierarchy steps and develop systemic effects accordingly, as follows:

I. PREVENT [R&D. ECO-LABELS, CONSUMER AWARENESS, DESIGN FOR DURABILITY, RECYCLABILITY, DEGRADABILITY]

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In this perspective, firms shall deploy actions in the field of research & development, design and consumer education, in order to reduce the amount of resources produced and disposed every year. Each material shall thus be studied, developed and treated to satisfy more user needs for a longer period of time. In particular, the first and second aspect may work in a complementary and synergetic manner.

On the garments project side, "eco-design" has become of paramount significance also in concrete business strategies. Traditionally considered as a way to extend the durability of clothes, it may now be analysed also in regards to the ease of recyclability, de-manufacturing or even degradability. Incentives shall thus be granted to designers favouring minimalism, fashion trends detachment, fibre blend reduction, single colour, aggressive finishing treatments and ability to separate garment parts. Regarding degradability, the following of the aforementioned principles will not be so stringent, whereas the more

straining requirement will be to use biodegradable fibres, sewing yarns and trimmings. In this viewpoint only, open-loop inputs may be favoured as well in order to provide more space for disruptive innovation and economic viability. All these aspects may be particularly supported by R&D, in the sense that the two departments shall work closely together, in order to progress in a consistent manner and solve each other's hurdles. Each material shall thus be studied basing strongly on the design targets, delivering enhanced use performances. For instance, if the target is about garment durability, an ever-green style shall be merged with a strong fibre, which may also be synthetic because in this case the environmental burdens of production would be balanced out along the years. Furthermore, in this case the choice of ecological and less resistant fibres would be even more counterproductive because the purpose for which the item was designed would not be satisfied and not being designed for recyclability or degradability the end-of-life potential of these resources would be limited. This reasoning shall always be supported by quantitative studies as a life cycle analysis in order to adopt the most suitable and sustainable option in each passage, always meeting market requirements thus having a sustainability strategy without compromises. Anyhow it goes without saying that usually a certain level of durability will be beneficial in all possible cases to reduce overall impacts and waste amounts.

Beyond all this, the whole system of prevention incentives for firms should be supported by quality control centres for the evaluation of products' eco-design and the application of eco-labels in order to explicit also to consumers the development process and huge efforts comprised in such a product offer. In these regards, brands and retail companies shall thus exploit multiple sustainable certifications and elaborate intelligently-studied campaigns for the addressing and consciousness raising of their specific clientele, harnessing the most fitting measures and communication channels to deliver the message.

II. REUSE [SECOND-HAND RESALE, LEASING, ONLINE PLATFORMS, REVERSE LOGISTICS, REPAIR SERVICE]

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This will be the second impact area of firms willing to drive circular and sustainable transitions as also aiming at receiving discounts on their extended producer responsibility fees. Reuse models especially seem to be the most easily combinable with existing strategies, the most profitable and the most brand equity enhancing option. Present statistics provide a strong support. According to Secondary Materials and Recycling Textiles [SMART], over 70% of world population uses second hand clothes (SMART Secondary Materials and Recycling of Textiles, 2020). Likewise, it is predicted that the second-hand market for clothes will double in the next ten years, and quality second-hand clothing will comprise a third of closet utilization by 2033 (Fibre2Fashion, no date).

The second hand market has been swelling in the last years, in particular regarding vintage and charity shops. According to a Humana recent article, 84% of consumers are more inclined at offering their used clothes to supply chains characterised by solidarity purposes. (Luppi and Strada, 2019) It will be thus beneficial to subdivide two different consumer typologies. One will pursue social sustainability and economic convenience objectives, whereas another will look for high-end vintage and almost-new collections to satisfy stylish desires and also support the sustainability claim. The former type won't have a high willingness to pay driving the necessity to reach economies of scale in volumes and centralise provision structures. On the other side, the latter type will require a much higher customer service level and products' quality state, pushing up costs but will also be characterised by a higher willing ness, potentially driving up profitability performances if commercialised and branded in the most accurate and fitting way.

Similarly, leasing and loyalty programs enable a greater profitability on the single garment due to the multiple uses and constant revenues, while also expanding widely the customer base thanks to a perceived higher convenience against single purchases. The typical customer in this case will be searching for continuous novelty and variety, but will achieve it without needing to follow the detrimental imperatives of traditional fast fashion businesses.

Hence, each brand shall be incentivised to choose the reuse model that best fits its clientele and that avoids cannibalisation issues, in order to receive the full profitability gains obtainable. In turn, they shall also be repaid for the enhanced costs and investments to bear, through a sufficient discount over the fee.

III. RECYCLE [COMMON EOL INFRASTRUCTURE]

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At this point, given the inefficiencies and technological rawness of textile recycling, single firms shall empower a centralized management system in order to subsidize and support the efficient progress of collectors, sorters and recyclers. As a matter of fact, the objective is to fuel the competitiveness of specific recycled inputs and let this section of the overall market grow. Basically, recycling will be beneficial both for all the materials that are not possible to be prevented or reused, as also for the coverage of determined fibre performance requirements. Biodegradable and less waste producing fibres shall be incentivised for the majority of uses. On the other side, sportswear and extreme conditions will always demand higher performances of functionality and durability, typical of non-renewable sources. Hence, in this field, it seems preferable to work on the improvement of recycling processes instead of searching for more degradable alternatives which are still not even in the sight of research and development centres.

In connection to this, as exposed above, the business case for collectors is worsening but it may be advantageous for recyclers, under the condition of an advanced and supportive sorting. Post-consumer quantities are increasing, export demand is decreasing and general quality is decreasing, in turn potentially increasing exponentially the fraction for recycling. For instance, once these recycling technologies are fully operational on the market, incentives for collection will increase, therefore the number of textiles available and suitable to be Fibersorted will be larger, hence, diverting into higher-value uses, textiles that are currently being down-cycled, sent to landfill or incinerated. (Circle Economy, 2019) Value maintaining closed-loop recycling, in particular chemical processing options, will thus represent a crucial solution in order to divert the majority of product and waste flows from landfilling and incinerating. Still, the waste hierarchy is clear and recycling EOL alternatives shall take place only subsequently to prevention and reuse. Intelligent collection and sorting processes will thus gain prominence in order to differentiate value and performance of each material, defining the relative 'Circularity Potential' and consistently the best choice for the sake of both economic and environmental sustainability.

Specifically, the research of a Reverse Resources report, also indicates that more than a quarter of the production leftovers are fabric pieces bigger than 18 inches (0.5 yards) which could still be usable in the factories, without recycling. Thus, waste hierarchy suggests that

recycling (to make new yarns) should only be applied on smaller cutting scraps, yarn waste and such leftovers which cannot be reused as fabrics, products or product details. In connection to this, further research will be needed into using the pricing scheme as a fair incentive to always favour the waste hierarchy for each type of leftover; the lower the solution found for each leftover in the hierarchy, the less suppliers will earn, and the more cost-efficient it should be for buyers. (Reverse Resources, 2017) This perfectly shows the need to modify competition patterns and business economic relations in order to trigger a widespread transition of players towards more waste hierarchy-driven tactics and strategies.

IV. RECOVERY

V. DISPOSAL

It is straightforward that these last two options shall be minimized as much as possible, through escalating fee levels.

Generally, it is important to underline how circular economy models provide a promising environmental sustainability enhancement, complemented by wide economic viability possibilities. The distribution of taxes will indeed grant a rising profitability trends in accordance with higher waste hierarchy principles deployment.

As a matter of fact, the design of this waste hierarchy-based classification of model features is also aimed at showing the power of servitisation. In this outlook, organizations should orient themselves towards the management of heterogeneity exactly as in service processes and quality should priory be embedded in the process. The more strategies align with the principle of 'prevention', the more they will need to extract as much value as possible from less resources, thus the more they will need to sell their performance, their credibility and their general service concept. The objective is to model the scheme in order to drive profitability in same upward direction of sustainability choices along the waste hierarchy. Moving from 'Disposal' to 'Prevention' there will thus be a declining trend in taxes, given the higher discounts, in turn in combination with rising value held in circulation and expanding servitisation rationales.

Accordingly, the whole structure supports a broad business modelling diversification, so that companies may accurately define their corporate strategies studying the greatest potential for each product stream. Regarding financial matters, the model further characterises the optimal subdivision of actions necessary for the sustainable development of the whole fashion industry. Ideally, companies shall thus concentrate on developing business models and innovative materials in accordance with the first principles, integrating reverse logistics in order to valuably handle as much as possible their own flows, on which they have much more data both on consumers as also materials, production and potential remanufacturing or repair processes. The common end-of life management infrastructure shall serve as second-best solution for all those materials which do not comply the quality standards required by prevention and reuse business models as well as all those wasted post-consumption garments which are not able to reach original producers and suppliers.

Additionally, this task subdivision solution lets less financially heavy, soft innovations under the control of the firms. Basically, digitalisation initiatives will still be subsidised but only through the discounts for firms able to extract concrete value and pollution reduction from such reductions as blockchain. On the other side, more financially burdensome, hard tech innovation, as collection structure and chemical recycling plants scale-up, will be directly subsidised with a central management in order to ease financing processes and remove the weight from single companies. It will be thus the magnitude of the whole industry, according to the specific polluter level/role, that will support these currently inefficient infrastructures.

3.2.3. *Product stewardship substratum*

The previous paragraph illustrated the driving criteria and business models desired, now the framework definition will deepen the detail level and shift toward regulatory technicalities.

The product stewardship approach's final objective will be to create the basis for win-win conditions. These shall be accomplished when all parties achieve an economic benefit sufficient to cover the risk of investments and strategic re-orientations, but also that the benefit gained in case of product stewardship implementation is higher than in absence of the value redistribution mechanism and enhanced stakeholders' cooperation.

The realization of such circumstances will be very challenging, given the heterogeneity of players and investments necessary for the transition. Tax levels shall be defined differently for a very broad number cases and relative factors relationships shall be thoroughly considered, aiming at the effective change in competition patterns, through modified economic drivers. For instance, a variable accounting treatment shall be provided to durable fibre options that may remain in the world as waste for hundreds of years against quickly biodegradable fibres that may take one month to decompose. All the specificities of case shall not be valued basing only on fibre type but according to life cycle assessments for the whole company offer and overall performances, thanks to an increased traceability and digitalised control.

Furthermore, in order to induce automatic mechanisms of economic convenience triggering the following of the waste hierarchy, the system should comprise the evaluation of average profitability achievable for each alternative. As additional example, prices for reselling leftovers to recycling must be pushed higher than down cycling or open loop price, but at the same time they should be low enough to render the purchase of recycled inputs convenient for fabric manufacturers and designers and besides this they should produce a profitability level lower that the one obtainable for reuse business models. Hence, the issue of possible cannibalization among strategic alternatives becomes a severe risk to manage. The effort will be thus pushed to individualise as much as possible the fees allocation. As Massarutto exposes, it will be necessary to produce specific signals in order to solve the market failures of asymmetric information and moral hazard. "*Each firm could be charged a personalized membership fee to collective PROs, taking into account the specific features of its product. If such a signal is not in place, the benefit of innovation will be shared by all, generating a classic free-riding situation.*" *(Massarutto, 2014)*

In particular, accurate fee definition requires the correct and pre-emptive understanding of correlated effective consequences.

First of all, once a diffused product stewardship scheme is in place, business-as-usual conducts shall be intrinsically discouraged, since they will keep producing large unnecessary amounts of clothes with virgin resources, thus disposing more and also paying more for this. On the contrary, circularity-oriented companies will produce in an absolute perspective less and with less virgin inputs, thus being advantaged by diverse fiscal incentives as discounts on product stewardship fees and VAT reductions. Basically, comprehensive pigouvian taxes inspired by EPR schemes will merge with sustainable business modelling incentives to result in an integrative regulative instrument, with the sake of solving market failures as pollution negative externalities, possible lemon market for recycled products, market power disequilibrium and barriers for closing financial gaps. In these regards, a system of standard KPIs will be

necessary to define performances and sum up the level of discounts to grant to circular companies, embodying a lean and clear process of meritocracy.

Indeed, sustainability and circularity-oriented firms will be benefitted with the improvement of their quality-price ratio and thus their competitiveness on the market. Unsustainable suppliers will be therefore even further disadvantaged, because cost chain reactions will likely take place. By paying higher fees, a polluter will be forced to reduce his internal margins or either worsen his quality-price ratio, pushing the preferences of customers towards other more aligned suppliers. Overall value chain actors will thus be triggered through an economic convenience criterion to supply themselves mostly from sustainable discounts-receiving companies, declining polluters' offers or accepting them only when prices are widely decreased, thus squeezing their profitability and long term subsistence. Collaboration among similar strategic outlooks will be automatically incentivized because if firms work together to develop own reverse or circular initiatives they all get discounts. This aspect in particular would support the resolution of asymmetrical relationships and incentive misalignment across the fashion supply chain.

The final question will be: What will happen when the majority of firms will be sustainable? There should be a mechanism of fees which adjusts themselves according to the general level of the market, thus following a rationale similar to a Yardstick Competition regulation. The underlying assumption is that if firms operate under similar conditions, they should, in principle, bear similar costs. The fees set by the regulator will reflect the average end-of-life infrastructure costs for the given population boundaries. For instance, as a consequence, a collector from country X will receive a level of subsidies calculated on the average unitary costs of all collectors comprised in the whole European geographical scope. In this way, collectors, sorters and recyclers able to reduce unitary costs at an equal level or lower than average costs set by the regulator, they will obtain an increase in profits and thus be highly incentivised. This whole system in combination with an increasing adoption of single firm circular initiatives shall likely drive the efficiency of the end-of-life infrastructure, thus directly lifting the financial burden of fees over supply chain players along the years.

Furthermore, diverse organisational issues shall be defined. The entity controlling the flows and managing taxes and subsidies shall be a Centralized European 'Product Stewardship Organization', i.e. a regulative body, not pursuing profits and avoiding opportunistic behaviours, also thanks to the implementation of blockchain digital layers for traceability and control. In addition, competition shall be designed among collectors in order to drive efficiency, according to the Yardstick Competition exposed above.

In particular, the whole European level has been chosen, due to the specific low value of clothing and textile waste, the inefficiency of the system and the dispersion of waste flows. In relation with such a widespread and blurred

supply and distribution network it will be preferable to centralize the management of end-of-life activities. Still it is relevant to underline the elevate fragmentation and globalisation of the fashion industry supply network which raises the necessity of deploying an extensive digital layer for the sake of tracing flows also relating to imports and exports, through the implementation of blockchain architecture and smart labels.

3.2.4. *Blockchain: the enabler*

"Blockchain technology is touted by many as the be-all-end-all solution for the digital transfer of value" (EY, 2019). Accordingly, the distributed ledger technology will in this case concretely act as the true enabler of a system that otherwise would be difficult to implement effectively. Decentralized control of flows and payments, in connection to smart contracts, will indeed provide widespread feasibility for:

- *Smart labels*: field-sensing Internet of Things labels, with an extremely flat chip, antenna and wires to be integrated with BC in order to create permanent, shareable and actionable records of products' digital footprints throughout the entire supply chain (Wang *et al.*, 2019)
- *Materials composition information accessibility*: secure and trustable data about the material mix, which holds on its own a wide significance among pollution factors, may be exploited both to detect low hanging fruit impact areas and also to gain brand equity given the higher transparency grantable to the growing slice of conscious consumers
- *Tracking for advice on contamination and recycling processes*: endowing recyclers with information about past production and re-processing processes as well as about garment's life phases and longevity may represent a game changing feature letting chemical recyclers adapt their processes accordingly and widely increasing effectiveness, producing higher quality outputs
- *Facilitated certification process*: Support eco-labels providing access to entire life cycle data. Indeed, as already mentioned, the Type I ecolabel criteria, according to the standard, should: i) include environmental impacts from the product's entire life cycle, ii) be established by a labelling organisation after consultation with several different

stakeholder groups, and iii) use quantitative environmental information based on Life Cycle Assessment (LCA). (Clancy, Fröling and Peters, 2015)Thus it would be possible to improve the reliability of certifications that are not always perfectly trusted and provide a more complete perspective, against the analysis of only upstream processes, as in the case of OEKO-TEX

- *Transfer of legal ownership in reselling*: the safe and traceable transfer of ownerships title will be particularly important for luxury segments' resale and rental programs, comprising trust, control and a higher customer service

- *Minimization of enforcement problems*: the convenience of the technology may facilitate the diffused acceptance of adoption and the enhanced supervision may facilitate the preventive identification of failures and opportunistic behaviours

Specifically, the application of blockchain integrated with the product stewardship scheme shall be designed to solve the inherent following matters:

- ***Enhance potential for trust, SC collaboration and thus integration:*** the majority of fashion supply chain stakeholders will be included in the network constituting the basis for beneficial connections, then the transparency and verifiability of each partner granted by the blockchain shall incentivise companies to partner up more in depth. In particular, worthy start-ups shall finally gain the deserved opportunities for collaborating with incumbents owning the financial, bargaining and technological power necessary to scale up innovative conceptions. In the same sense, generally valuable small firms shall be facilitated in the obtainment of financing and certifications. These circumstances would certainly increase the overall innovation level potential.

- ***Connect usually separated players in secondary markets:*** Similarly, as for the enhancement of collaboration intra-fashion value chain, transparency and verifiability raise the trust also among more distant enterprises

- ***Minimise free riding issues***

- ***Facilitate management of cross border flows***: the implementation of smart labels and the application of blockchain also to wholesalers and retailers shall support the tracking also of imports and exports

- ***Facilitate product deletion choices***: the advanced understanding of demand patterns and determination of the most fitting moment to shift from one product offer to another shall avoid the declining phase of the product cycle curve

- ***Enable direct rewarding***: A logical application of smart contracts is the establishment of monetary rewards automatic activation upon customer take-backs in case of resale as well as rental business models or high purchase levels in case of loyalty programs. This speed in remuneration processing will likely improve the satisfaction level of consumers and the efficiency levels of front-office services

- ***Facilitate end-of-waste criteria evaluation***: The availability of massive data about the actual state of production processes, products and business models in place eases the deployment of mean trends analysis, present technologies and best fitting criteria for the management of waste streams into the circular ecosystem. Accordingly this will also minimise issues for the inspection processes of quality control and certification centers

- ***Achieve higher social sustainability performances through SC integration and higher control both on companies and products:*** traceability data requirement will include also social sustainability metrics, driving a more transparent supply chain even for the most remote tiers

- ***Implement deep learning practices through the exploitation of RFID or genetic marker technologies:*** support the improvement of estimates regarding post-consumer materials contaminations and general products' conditions, defining the potential for circular solutions and for more accurate and automated marketing and branding activities to more effectively trigger customers, with the possibility to steadily track engagement. In particular, the use of blockchain also solves the hurdle of maintaining consumers' privacy in RFID applications, thanks to the feature of anonymity

- ***Exploit decentralized control of BC to minimise surveillance requirements in the PS scheme***

- ***Shrink the dark space of information unavailability during the use phase***: online platform-based customer care support and rental systems may gather data about use phase on a constant rhythm, while also assuring privacy by maintaining the anonymity of users

Aiming at the satisfaction of these primary requirements, the technical design of the architecture shall be studied accordingly.

Generally, in a blockchain system, a list of transactions is recorded onto a ledger over a given period, creating a 'block'. As each transaction occurs, it is put into a block. Each block is connected to the blocks before and after it. These blocks are mathematically 'chained' together through a hashing function; – we could think of a hash as a digital fingerprint of data to lock it in place within the blockchain (Laurence, 2017). When a new transaction or an edit to an existing transaction enters a blockchain, generally a majority of the nodes within the blockchain network must execute algorithms to evaluate and verify the history of the proposed individual block. If a majority of the nodes come to a consensus that the history and signature are valid, then the new block of transactions is accepted into the ledger, and a new block is added to the chain of transactions (Laurence, 2017). Anyhow, in blockchains for business and specifically for supply chain is mining is not necessary. Good behaviour (no cheating) can be enforced by signed agreements that specify how participants are to use the blockchain system. The bitcoin "proof of work" consensus method is then not needed. All users of the blockchain must agree on the existing blocks in the chain and the new blocks that are added. (O'Byrne, 2020b) Signed agreements will thus need take into account all diverse opportunistic behaviours and free-riding possibilities.

Furthermore, in respect to the complexity of the fashion supply network, it is relevant to underline that the effectiveness of the system and of the value extraction processes will reach full potential only if designed according to an end-to-end approach. The setting of the blockchain will thus be of hybrid typology, thus balancing the efficiency and security of a private one with the effectiveness and deep learning potential of a public one. The reason stays also in the fact that it is impractical to store large amounts of transactions with large amounts of associated data on a public blockchain primarily because the throughput of public blockchains is small: in the order of 50-1000 transactions per minute. Beyond scalability, an important concern is indeed the energy consumption of blockchain transactions as well as their cost. (Evrythng, 2018) Basically, upstream the access will be granted only to accepted supply chain partners, whereas downstream the access will be permissionless towards retailers and consumers in order to provide credibility and information to better drive consumption choices, while also modifying competition patterns.

The accessibility of data relating to whole garments and to all inherent inputs will then follow a tree diagram structure as shown in figure 31.

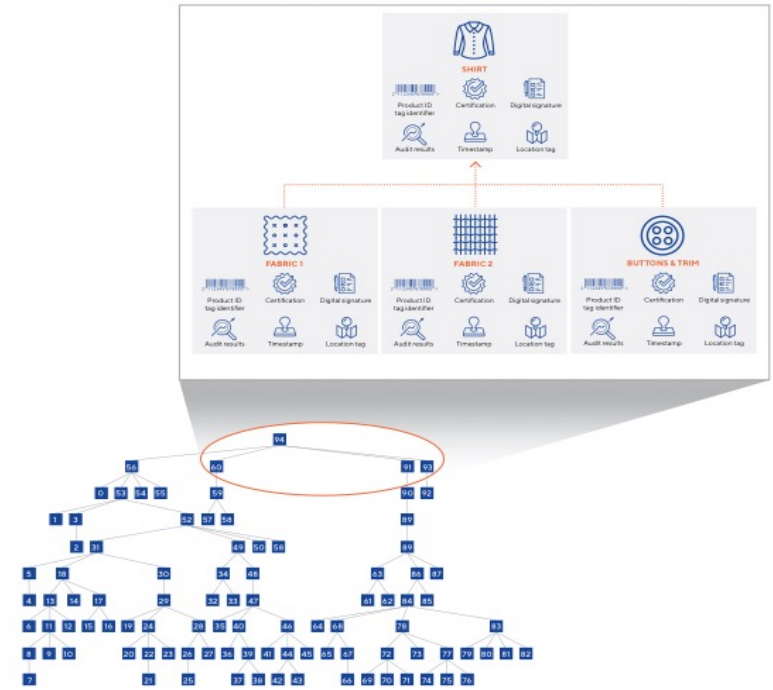

Figure. 31 - A hierarchical representation of product-level provenance data capture (Patel et al., 2018)

Specifically, the informational set to save on each block will need a specific structuring as well. It will serve as information basis for general tracking and transparency, as also for an analysis of KPIs evaluation for the sake of determining the discounts and the best fitting use and end-of-life strategies, according to higher economic and environmental sustainability.

Taking as reference an existing scheme of "Categorical metrics of information to include on individual blocks" (Rusinek, Zhang and Radziwill, 2018) – See **Section 1.2.7.** - and adding specific required features, the resulting data requisites are displayed in table 2.

Metric	***Information to include on blocks***
Economic	Smart contracts – Executed transactions (payments, deliveries…)
	Bank access to network
	Product Stewardship Organisation access to network
	Insurance information
	Lifespan of material or garment
	Recycling cycles undergone
	Durability estimation (fibre length…)

	Market resources and commodity prices
Environmental	Relevant environmental certifications (e.g., EU Ecolabel, FSC certification, chemical certifications like OEKO- TEX, GOTS, Cradle to Cradle)
	LCA impact data
	Higg MSI impact data
	Inputs from nature
	Inputs from technosphere
	Amount of energy used
	GHG emissions
	Waste, by-products and co-products produced
	Biodegradability, compostability
Social – consumer education	Relevant certifications (e.g., Fair Trade, GOTS, OEKO-TEX, SA8000)
	Living wages
	Worker age and hour restrictions; freedom to organize
	Gender equality
	Responsible care instructions
	Responsible disposal instructions
Functional	Date of production
	Intended use
	Capabilities (e.g., heating, cooling, data tracking, water resistant, antimicrobial, UV protection)
	Design for X (e.g., environment, disassembly; privacy)
	Warrantee information
	Repair information
	Quality control information
	Recycling cycles undergone

Table. 2 - Blockchain information requirements

These information categories shall also benefit the facilitation of certification processes, providing high traceability and reliability of data. Upon the extraction of multifarious data, smart contracts will play a relevant role in the productiveness of the proposed framework. First of all, they shall be used to update manufactured outputs data for each player consistently in time with concrete batches production, in order to directly trigger the payment of fees at the end of the year. Further on, cloud computing processes shall support the allocation of subsidies to end-of-life management operators and incentives for producers. Such an accuracy in information facilitates indeed the application of an exhaustive classification of data and further customisation of economic treatments.

In particular, discounts for long term sustainability oriented companies shall be defined according to a system of KPIs, mirroring diverse circular and sustainable dimensions as well as the savings in flows that would not need to be managed within the common end-of-life infrastructures of collectors, sorters and recyclers. This individualisation of fees and discounts shall likely provide higher effectiveness potential in aspired outcomes, because each supply chain actors would be able to always see the direct benefits of his sustainable actions, thus reduce their uncertainty level and be further triggered.

KPIs:

- *Eco-design for durability*
- *Recyclability*
- *Degradability*
- *Easiness of reselling*
- *Zero waste processing*
- *Chemical risk*
- *Water depletion*
- *Transportation efficiency (role of distances within networks and flows optimisation)*
- *Reliability*
- *Consumer awareness raising*

The guiding principle is always a shift from a volume focus to an industry that is incentivised on quality, in which garment durability and number of uses would become the critical enablers of commercial viability. In addition, actions shall be taken in order to educate and facilitate the purchasing choices of consumers. For instance, online scenarios usually entail more environmental benefits compared to offline scenarios due to the closer package pickup-point to customers (one third of the distance). Hence, this underlines the role of

distance and the importance that locations of stores and/or pickup points are close to customers or accessible by public transportation (Zamani, Sandin and Peters, 2017). Hence, generally these Key Performance Indicators align with the measurement requirements put forward by a recent European report (European Environment Agency, 2016); where five main categories have been introduced:

a) *Reducing input and use of natural resources*: the main aim is to reduce the erosion of the natural ecosystem currently caused by linear models. In brief, the objective is to deliver more value from fewer materials. The direct consequence is also the preservation of natural resources, with an efficient use of raw materials, water and energy;

b) *Reducing emission levels*: this refers to direct as well as indirect emissions;

c) *Reducing valuable materials losses*: the implementation of closed loop models to recover and recycle products and materials through reverse flows allows preventing waste production, minimizing incineration and landfilling and decreasing energy and material losses;

d) *Increasing share of renewable and recyclable resources*: the aim is to cut emissions throughout the full material cycle through the use of less raw materials and more sustainable sourcing; another issue is to reach overall less pollution through cleaner material cycles;

e) *Increasing the value durability of products*: this goal can be reached through the extension of products' lifetime, the adoption of new business models based on use-oriented services (e.g. product leasing and pooling), the re-using of products as well as components, and a high diffusion of material recycling.

In respect to this performance dimensions, the optimal combination for the effectiveness of environmental and economic sustainability enhancement frameworks, shall comprise the use of blockchain traceability in connection to eco-designed rental service. Usage data may be exploited to improve both the offer and marketing activities, as also the related margins. The logic bases on the fact that renting options intrinsically incentive a design for higher quality and life-expectancy, thus raising the value potential of each resource. This would then connect to the fluid rewarding feature of specific smart contracts, in order to align customer demand and satisfaction to the offer.

Accordingly, the whole framework proposed will be tested on a case study of a Dutch jeans start-up, which embodies most of the circular fashion principles and is letting its leasing revenue stream grow ceaselessly.

3.2.5. *Framework Scheme*

In summary, the novel proposal regards a product stewardship framework supported by a blockchain digital layer, aiming at the full adoption of closed-loop business models for the fashion industry long term environmental and economic sustainability.

Specifically, the base principle is the subdivision of responsibilities and flow typologies between single companies and centralised infrastructure initiatives. Each of the two parts will control the actions most fitting with its characteristic, financial and operational power. Single firms will thus be incentivised to act on the first two principles of the waste hierarchy mainly through soft tech innovations. On the other side, the centralised infrastructure will need to be subsidised to deal with hard-tech financially burdensome innovations in an aggregate way, expanding secondary markets and optimising the reverse supply chain structures.

In order to achieve the objectives fixed above, the principles of economic convenience and polluter-pays shall be integrated with a much more accurate differentiation and individualisation for the allocation of subsidies, fees and discounts among cases of application. The fees will thus be related to the single product, included in thoroughly differentiated categorization, and will also depend on the production levels and sustainability performances of each firm. Furthermore, as differentiation factor against the existing French EPR case, the level of coverage of fees is designed to vary according to supply chain position in addition to waste volumes, given the diversity in bargaining power and ability in investing or also carrying out innovations. As shown in figure 32, the stages paying higher percentages will be the fibre production and more importantly the design & distribution stage, since brands are targeted as the key to propel revolutions both upstream and downstream. In particular, the allocation of fees to the use phase is given by the transfer of the additional costs that the retail brand will have to bear and will thus partly include in the price towards end customers.

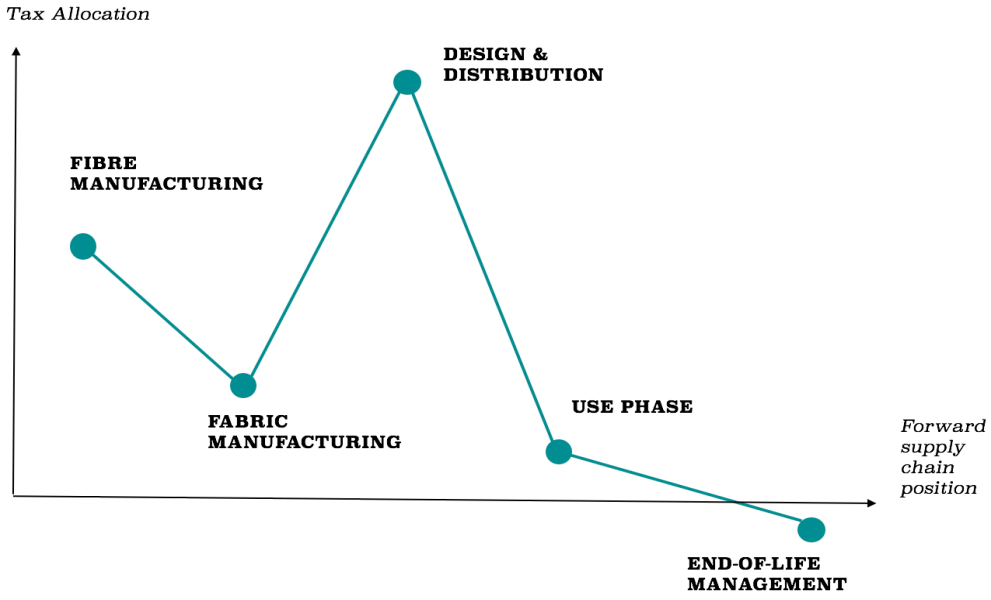

Figure. 32 – Differentiation in fees allocation according to Polluter-Pays-Principle and supply chain position

In relation to the market failures exposed in the previous sections, the framework shall adjust them by incentivising the following factors: power disequilibria through more transparent, symmetric and trusty supply relationships; negative pollution externalities and overproduction through the allocation of fees, thus the increase of individual firm perspective costs aligning it with social costs to bear; asymmetric information through signalling options as green certifications and reputable alliances; transaction costs through blockchain efficiency and elimination of intermediaries.

In these regards, as anticipated in the methodology section, since the framework will represent a combination of traditional EPR logics together with individual sustainability actions, in the forms of eco-design, reuse business models and reverse logistics, the logical algorithm used to define taxes, discounts and financial impacts will be the following:

1. *Cover operating costs for end-of-life management (assuming that everything that is produced is destined to pre- and post-consumer waste)*
2. *Define resulting figures net of revenues*
3. *Distribute fees weighting according to firm's waste volumes and supply chain position impacts*
4. *Define discounts for producers according to impacts (volumes) avoided from EOL common management*
5. *Define subsidies in order for EOL actors to have a positive breakeven*

6. *Assess delta NPV of circular investments vs Business-As-Usual for each actor (at different levels of application of the model)*
7. *Assess supply chain effects*

Among the supply chain effects, the other features of the model were designed also to empower customers through information availability, attempt to drive their care habits and decisions for the end-of-life management of each garment. Furthermore, given the structure of a hybrid blockchain, the scheme aims to act also in the formation of innovation hubs. Targeted consortiums would have indeed the power to accelerate progress by combining resources from multiple parties and aligning the key players needed for success in a focused effort. Supply chain effects shall thus be widespread from end to end, sizably changing production, consumption and competition patterns. As shown in figure x, the deployment of waste hierarchy principles applied to the fashion environment with specific business models and operational settings, shall also drive an enhancement in profitability and value held in circulation, as well as supporting the trend in servitization. The more initiatives are drawn by companies towards waste prevention and reuse and thus towards the sale of performances, the lower will be the fees to pay. With this incentive scheme, value would be effectively moved and redistributed across the whole industrial ecosystem.

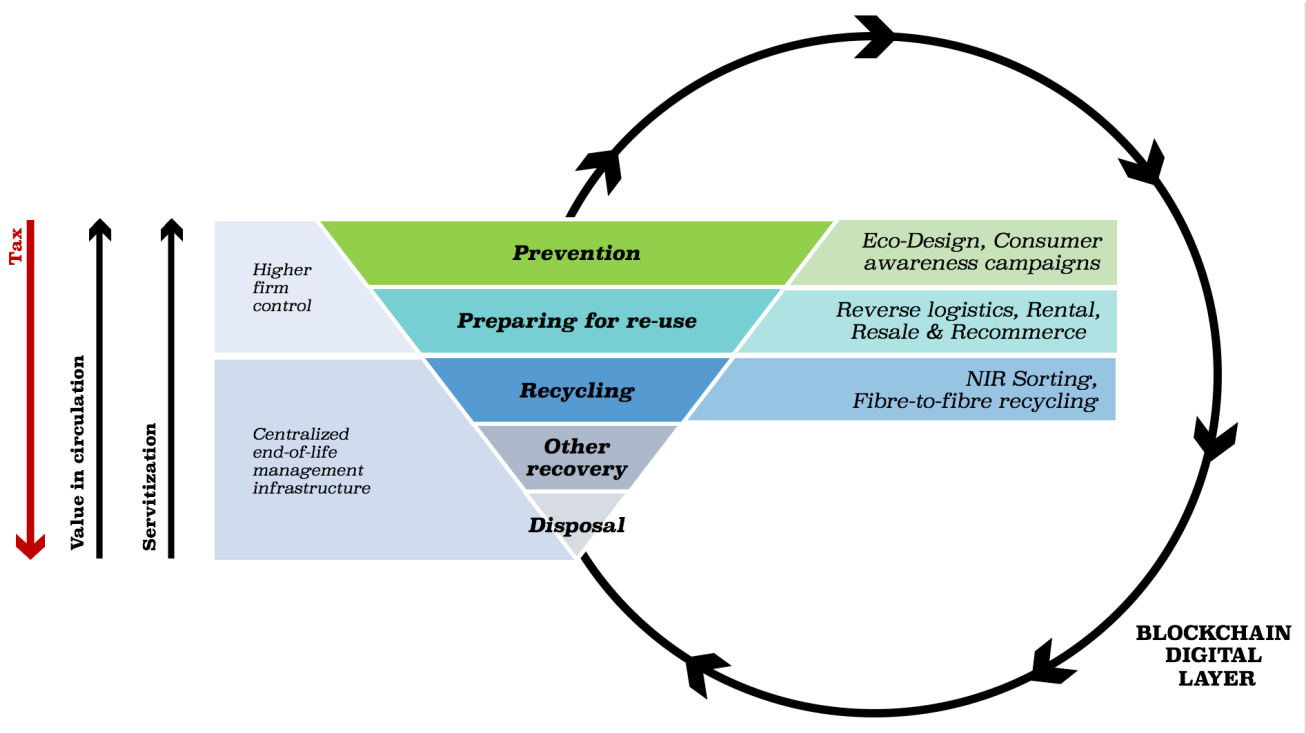

Figure. 33 - Incentives scheme diagram

Section 4

TESTING, FINDINGS & DISCUSSION:

Case Study Analysis

This section aims at exemplifying the application of the model as well as both quantitatively and qualitatively assessing the outcomes achievable in the determined case study under investigation.

As a matter of fact, the synergy among circular economy, product stewardship and blockchain constructed and embodied within the model embraces a theoretically wide potential of effectiveness in incentives towards industry players. However, the validity of related propositions may only be acknowledged only if tested empirically. The evaluation shall regard a specific case of implementation, which bases on a defined sub-set of data and may provide unvaried results if repeated with the same process. Beyond the framework's conceptual features, the two-fold analyses testing will be used to investigate the concrete levels of economic and environmental sustainability obtainable with the establishment of such a product stewardship scheme throughout the whole fashion value chain. Specifically, given the complexity and heterogeneity of business models, products and systemic flows setting typologies produced by the framework, the implementation process will be subdivided into 3 steps, adjusting to a gradual addition of modelling building blocks.

The scenarios analysed in each of the two economic and environmental validation assessment will be thus 4:

- **Business-as-usual**: Case in which the industry follows the current strategies. The general trend will reasonably continue with scarce and isolated examples of sustainability champions thriving to have a positive impact on the fashion environment and the majority of companies will keep being driven by traditional principles of economic convenience and denial of burdensome investments.

- **Circular Stage 1**: Case of basic product stewardship scheme establishment, characterised by the sole collection of fees according to the polluter-pays-principles and directing them to collectors, sorters and recyclers, in order to scale up the reverse supply chain infrastructure and optimise it. Companies would be disadvantaged by producing in an unsustainable manner, but would not face concrete incentives for specific improvement strategies. In this way end-of-life management infrastructures would be held at breakeven but companies would not see the direct benefits of their investments' actions, being thus disenchanted to move forwards internally. Blockchain would be used for the advanced traceability of flows and for the determination of Circularity Potential dimensions.

- **Circular Stage 2**: Circular Stage 1 conditions combined with the development of individual company initiatives, as reverse logistics, resale and rental business models. Here individualised discounts shall serve as effective incentives for firms, in order for them to start a change management process, change their value proposition and generally collaborate in the advanced recovery of value. Blockchain would serve the previous functionalities, while also providing efficient rewarding of customers through specific smart contracts.

- **Circular Stage 3**: Circular Stage 2 conditions combined with the application of eco-design principles and consumer awareness raising initiatives, thus fulfilling the first principle of the waste hierarchy through waste prevention. In this way volumes produced and disposed would be much less, weighting less on the common end-of-life management infrastructure, and supply chain stakeholders would cooperate more towards the sustainability enhancement of the overall ecosystem. Blockchain would serve the previous functionalities, while also providing information transparency for the support of intra-firm product deletion decisions as well as of consumer conscious purchase, care and disposal actions.

In these regards, the objectives of the validation process would be the following:

- ✓ Test the effectiveness of the framework conditions in incentivising more sustainability- and circularity-oriented producers
- ✓ Verify pareto efficiency achievement across the whole value chain
- ✓ Demonstrate the profitability trend enhancement against business-as-usual scenario
- ✓ Demonstrate the gradual improvement of outcomes according to rising completeness of framework implementation, thus moving from 'Circular Stage 1' to 'Circular Stage 3'. This purpose shall entail also the verification of possible pitfalls of traditional EPR systems in providing the proper incentives to companies.

As already mentioned, the validity of the model shall achieve higher levels once innovative supply chain-based blockchain, NIR sorting and chemical recycling technologies will be available at scale on the market. On that account, the testing will be deployed over five years starting from 2025 till 2030, which is what many statistics used as termination.

As stated in the methodological section, for the sake of proving testing objectives and providing impactful analytical outcomes, the primary product chosen is a pair of jeans, i.e. the emblem of fashion industry economic, social and environmental boundaries annihilation. In particular, jean has undergone constant evolution to remain sustained in fast-changing fashion and is characterised an everlasting love from consumers. For instance, advantages of denim fabrics are high durability, excellent strength, all-time fashion and appealing aesthetics. As a consequence, denim is one of the major sectors of the textile industry and is manufactured by more than 15 countries around the world, producing an intricate clew of flows before retail stage (Amutha, 2017). Before landing on our shelves, each denim garment travels indeed an average distance of 65,000 km, emitting 20kg to 40kg of CO2 (Renou, 2019).

According to the lifecycle analysis carried out by Levi Strauss & Co in 2015 on one of their most classic products, i.e. a Levi's® 501® medium stone wash jean, the most significant impact areas are consumer care and cotton cultivation. As a whole, the entire lifecycle of one single pair of Levi's® 501® jeans equates to 69 miles driven by the average US car producing climate change (33.4kgCO2-e), 3 days-worth of one US household's total water needs alimenting the severe water consumption (3781 litres), the total amount of phosphorous found in 1,700 tomatoes causing the phenomenon eutrophication (48.9 g PO4-e), as well as 12 m^2/year land occupation (Levi Strauss & Co, 2015). Indeed, although cotton fields make for only 3% of all cultivated lands, cotton is the 3rd biggest water-consumer following rice and soybeans and is conversely mostly cultivated in countries with water scarcity. (Duraisamy and Periyasamy, 2018) Furthermore, cotton is also unusually fragile and can easily get annihilated by diseases, insects and pests causing the need for extreme amounts of pesticides and fertilisers, while simultaneously provoking dreadful health diseases among farmers. Likewise, also the denim manufacturing process sometimes involves dangerous industrial practises, as sandblasting. (Denim Première Vision, 2019a)

Relevantly, all these alarming impacts comprised within the lifecycle of such a beloved clothing item, demonstrate the significance of this low hanging fruit. As a matter of fact, innovating and improving related inputs, processes and care habits has disproportionately large and widespread effects. Accordingly, a pioneering brand in the fight for this revolution represents the basis of the case study on which this validation process will take root. The power of its game changing business model will be made evident in the following paragraph.

4.1. CASE STUDY: MUD JEANS – CIRCULAR VALUE CHAIN

MUD Jeans is a sustainable and fair trade certified denim brand based in the Netherlands founded in 2013, aiming to "make good quality, ethical jeans available to more people." Their name originates from mud being it a mixture of water and any combination of soil, silt, clay, which plays an important role in the ecosystem but most importantly, it can be recycled eternally. (MUD Jeans, 2020a) This concept thus metaphorically drives their whole mission as key fashion industry player, which is to: "radically change the fashion industry by taking the most popular fashion item in the world, a pair of jeans, and producing it in the most sustainable way without losing a timeless sense of style. This is how we make it extremely easy for our consumers to participate in our mission." (MUD Jeans, 2018).

Envisioning a world without waste, the Dutch brand implements a beneficial variety of circular business model patterns, which may be categorised into (Wijnen, Groenestege and Business Models Inc BV, no date):

- **Circular Sourcing Pattern**: 40% inputs come from recycled denim, the other 60% from bio-organic cotton. Additionally, it uses trash-free packaging which can be reused up to 20 times.

- **Recondition Pattern**: Worn and leased jeans are turned into vintage jeans, accompanied by a higher customer care and personal names given to each pair of jeans in order to raise principles of familiarity and individuality.

- **Performance Pattern**: Eco-design principles are exploited to develop a long-lasting, recyclable and stylish product. This further combines with a growing leasing business, which currently represents 25% of their business.

An additional benefit of manufacturing a product that lasts is that customer service levels will intrinsically rise, for the sake of achieving the aspired performances. In these regards, the further step regards where-to-play choices in respect to customer segments, thus moving from conscious early adopters to

the early majority mass. This transition is indeed supported by the fact that their active community which leads to word of mouth growing the customer base as well as sharing their vision and mission. On the other side, they also benefit from a very strong value network with partners that share a similar vision and help each other succeed in bringing circular fashion to the market. These driving forces together may actually enable the desired decoupling of economic growth from social and environmental impact. Accordingly, MUD Jeans strength points may be systematised as follows (Wijnen, Groenestege and Business Models Inc BV, no date):

- *Expanding target customer base*: "Hip & Healthy" and "Intellectuals" consumers represent 11-12% of the European market, amounting to about 30 million and forecasted to grow in the coming years

- *Circular design and vintage re-conditioning*: Support the reuse of resources through many technical details – For example, labels are printed to facilitate the de-manufacturing of the final product

- *Multiple certifications*: The brand already obtained B-Corp, BCI, GOTS, Fair Wear Foundation, Cradle-to-Cradle, OEKO-TEX and others, providing a valid signalling of their products' quality, their organisation ethics and strategic intentions

- *Personalisation and customization*: Digital marketing and enhanced traceability are used to turn data into actionable insights and keep each possible consumer or supplier interaction relevant

- *Recurring and foreseeable revenues combined with high levels of customer retention and engagement*

On the downside, embodying such an innovative business model entails also various barriers to stand (Wijnen, Groenestege and Business Models Inc BV, no date):

- *Circular business models are treated as traditional in respect to taxes*: MUD Jeans has to pay twice the VAT on recycled fibres and reused resources

- *Dependence on subsidies and external investments*: Positive organic profitability was still not met, thus depending on external stakeholders

- *Need to save data in a safe way according to regulations*: which is often difficult to achieve

- *Time extension of leasing model economics*: High product costs are incurred upfront, while full revenues are realized much later in time

- *Higher fixed assets than competitors*: All leased jeans remain and weigh on the company balance sheet, rendering it more difficult to raise funds

- *Commercialisation gap*: Lack of investors to double down on growth

Still many of these hurdles may be solved through the implementation of the aspired blockchain-enhanced product stewardship framework, granting financial support for business expansion, higher security, transparency and traceability of data determining easier innovation and financing processes. Indeed, such a reality would receive much higher fiscal incentives than the rest because of its comprehensive compliance with the first 3 principles of the waste hierarchy.

Furthermore, MUD Jeans's processes generally reflects the top five actions to boost the useful life of jeans, in a perspective of Design for Longevity, according to a WRAP report, are (WRAP, 2015a):

- ✓ *Using ozone bleaching, laser engraving and resin finishes to create the desired effects with a lower environmental impact;*

- ✓ *Enhancing fabric strength and surface quality by applying sustainable dyeing, bleaching and surface treatments;*

- ✓ *Applying traditional, robust manufacturing methods and mass customization strategies to products;*

- ✓ *Educating consumers about the unique characteristics of denim and how to care for it and repair, re-use or repurpose it; and*

- ✓ *Creating emotional attachment through ethical sourcing and production, no waste and craft design approaches.*

CIRCULAR VALUE CHAIN:

In accordance with the last of these principles, also the upstream supply chain actors have been chosen consistently to MUD Jeans' vision and mission. In order to assess the widespread outcomes of the framework's implementation, a limited hypothetical value chain was conceived, choosing the actors basing on availability of quantitative data, alignment with MUD Jeans strategic perspectives, pertinence to the European apparel sector scope of analysis. Specifically, in order to simplify the complexity and fragmentation of a denim supply network the testing will focus on only one fibre producer and one fabric producer, both maintained in anonymity. Whereas, on the downstream an integrated collector and sorter has been chosen to represent the common value recovery infrastructure.

The specific fibre producer (FIB) is a large international viscose-like fibres and yarns manufacturer which will represent also the chemical recycler, given its patented process, already functioning at commercial scale and promising wide potential of performances for the forthcoming years. With revenues of more than 2 billion € and a workforce of more than 7000 employees, this implementation candidate demonstrates a great market power and ability to effectively drive the sustainable transition once a fiscal supporting scheme is in place. As mentioned in the interview with Circle Economy, man-made fibre manufacturers face less recycling stumbling blocks because they can build upon their knowledge of polymerization processes. (CE) These characteristics facilitate the provision of a product comparable with virgin fibres in relation to price and quality, once reached full scale. Furthermore, according to the VF interviewee, viscose is specifically one of the materials that will be employed the most in future. "First of all because all the cotton and high-cellulosic materials going through chemical recycling will become a viscose-like output. It will be thus necessary to integrate it on the market, although is covers for now only a niche of the textile markets, mainly for the women segment, given the feminine look & feel of final fabrics. We are carrying outs various researches to understand which would be a fitting mix, since within recycling, according to the inputs used, each time a different viscose nuance comes out. Generally, since cotton cultivation is so extensive and is conflicting with food production, viscose is surely of increasing interest as cotton substitute. (VF)

Further on, the fabric producer (FAP) defined is a historical high quality sustainability-oriented denim mill, which is investing widely on circular economy and blockchain projects. It perfectly represents the positions in the middle of the supply chain, in regards to the limited innovation and financing power on their own.

Finally, the last actor will be the integrated collector and sorter (CS). It is the largest recovery player in Italy and is drawing much interest for the establishment of proper product stewardship frameworks. Collection is done mainly through road transportation gathering used clothing from special containers across the cities. Sorting is then deployed through a manual process on the materials that are not sold as original or disposed of.

4.2. FLOWS ESTIMATION PARAMETERS

This chapter aims at introducing the two-fold analysis carried out, synthesizing the basic modelling assumptions that were then further deployed in both tests. In relation to the novelty of single topics as well as of their integration, the process of finding proper quantitative data was not linear nor flawless. It therefore necessary to lay out various hypothesis, merging different information sources and finding consistent estimates for diverse classes of data. The result will represent an artificial prototype of reality, embodying limitations for the analysis. Still, aiming at higher reliability of outcomes, the data gathering process mixed primary information with compatible secondary information, thus testing if each data input may be in line or not with the trends unfolded by reference industry stakeholders' reports and statements. For instance, the geographical horizon of estimates has been adapted to the European case study. In some cases, global facts and figures are thus applied to the hypothetical value chain constructed in the previous chapter. Furthermore, since the testing covers five years from 2025 to 2030, it is built on future forecasts that may prove right or not. The purpose is to build the foundation for further research and development, so that when the technological substructure will be set, it will be possible to extract the whole potential value obtainable.

Beyond this, aiming to gather more generalizable results, different fibre inputs will be analysed in an aggregate way, given also the relevance of fibre blends on the textile market. The specific final product studied is thus a jean made of a blend of 67% of cotton, 17% of viscose, 14% of polyester and 2% elastane[i], requiring 1,5 yards[ii] of an assumed 60" wide fabric[iii] with an average weight[iv] of 13 oz/ya^2 for each unit produced. The mix of fibres was selected among the common standards of jeans production and the choice build upon the need to provide higher durability to the clothing item. Beyond the significance of blends in current fashion practices, this option was also selected basing on the assumption of next future development of chemical recycling technologies, which shall thus enable the depolymerisation and gradual separation of fibre typologies.

Accordingly, the circularity of this product is then tested through different flows estimations for each assessed scenario, in relation to reuse options, downcycling, closed-loop recycling and disposal, i.e. landfilling or incinerating. Percentages refer to the quantities collected yearly in each assessment scenario by the end-of-life management player. These are then assumed to be likewise transferred across the value chain, according to the European settlement and the necessary internal consistency of the implemented hypothetical case study.

The Business-As-Usual scenario is characterised by current estimates available from Humana reports (HUMANA People To People, 2018), which are then

prolonged through linear tendency functions in order to define future values, as shown in figure 34.

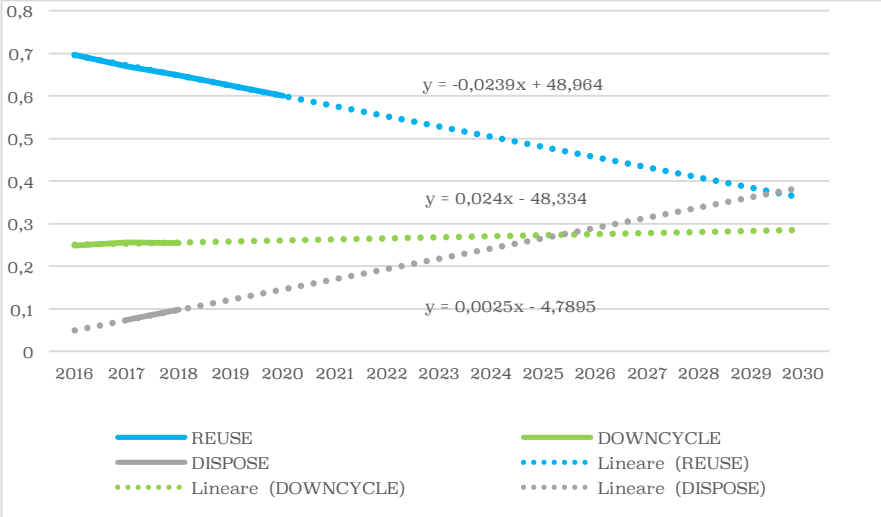

Figure. 34 - Reuse, downcycling and disposal flows forecasts

It has to be noticed that currently closed-loop flows are negligible among Humana volumes, given the lack of business partners as well as available, effective and efficient technologies for any type of fibre. The 1% determined in 'A new textiles economy' report (Foundation, 2017) is thus added upon and kept constant since in this scenario lacks of any external support for the development of sustainable alternatives and reverse supply chain optimisation. Finally, the results found are then renormalized to reset consistency of percentages.

Furthermore, for the sake of further calculations simplicity, percentages are subdivided in reuse on the one side; whereas downcycling, closed-loop and disposal figures refer to the percentage of not reusable materials, thus to (1-%Reuse). The timely development of values is shown in table 3.

Business-as-Usual	***2025***	***2026***	***2027***	***2028***	***2029***	***2030***
Reusable	**0,512**	**0,490**	**0,467**	**0,444**	**0,422**	**0,400**
Downcycle	0,496	0,477	0,460	0,444	0,429	0,415
Dispose	0,494	0,513	0,530	0,546	0,561	0,575
Closed loop	0,010	0,010	0,010	0,010	0,010	0,010

Table. 3 – Business-As-Usual flows assumptions

Moving on, Circular Stage 1 entails the establishment of the first step product stewardship framework, i.e. the subsidising of recovery infrastructure and reverse supply chain optimisation. The related flows will thus initiate from the Business-As-Usual scenario but then the share of non-reusable materials will be subdivided differently. As a matter of fact, the first achievement reachable through such a system is the deployment of pure, controlled and unmixed pre-consumer waste into closed-loop recycling processing. These industrial excesses, particularly favourable to textile recycling effectiveness, usually comprise: unsold or damaged garments; batches not shipped in time, not matching quality requirements or blocked at customs; cutting scraps, roll ends, overproduction, sample garments; surplus, defected or undyed fabrics; dirty or too short fibres; defected yarns (Reverse Resources, 2017). Closed-loop flows will thus rise from 1% to an assumed 12% of produced volumes (Foundation, 2017). Furthermore, it is considered that such a supporting scheme would facilitate optimised collection and sorting, resulting in ultimate potential outcomes in 2030 which at least maintain the current performances. Final disposal and downcycling percentages are thus calculate referring to today's proportions within Humana flows. Relating to the volume of non-reusable materials, the results would be a 27,84% in disposal options and a 72,16% in open loop recycling. After this, the advancement of fibre-to-fibre recycling technologies has to be added in the examination as well. Hence, assuming that landfilled and incinerated materials will still be difficult to be recovered, the percentage to vary will be the one of downcycling. As mentioned, potential ending value of closed-loop streams will be 12%. Consistently, the potential ending value of open-loop streams will be 60,16%. Basically, values will thus begin from the ones characterizing the Business-As-Usual scenario in the first year and will then develop linearly towards the ultimate results just displayed, as shown in table 4.

Circular stage 1	***2025***	***2026***	***2027***	***2028***	***2029***	***2030***
Reusable	**0,512**	**0,490**	**0,467**	**0,444**	**0,422**	**0,400**
Downcycle	0,506	0,526	0,545	0,564	0,583	0,602
Dispose	0,484	0,440	0,397	0,354	0,311	0,278
Closed loop	0,010	0,034	0,058	0,082	0,106	0,120

Table. 4 - Circular Stage 1 flows assumptions

Secondarily, Circular Stage 2 is characterised by the integration of reuse strategies, such as the development of individual firm reverse logistics, rental and resale business models. This step will thus modify the structure of streams relating to both reusable and non-reusable materials. Given the fact that companies have a higher control on the quality of their products and benefit

also from periodic repair in rental systems, they shall also be intrinsically incentivised to enhance the durability of clothes in order to extract more value from their business models put in place. As a consequence, the expectation is that reuse level will be kept at least constant. For what regards non-reusable flows, it is assumed that these will logically start from the percentages characterizing the Business-As-Usual scenario in the first year, but will then develop towards the performances achieved in Northern countries, which represent a reference in this field. Through an intelligently improved collection, both on a common infrastructure base and on an optimised firm reverse logistics system, in addition to the use of Fibersort technologies, an Interreg project report displays flows that, if referred to non-reusable materials, correspond to 60% potential closed loop recycling, 30% downcycling and 10% disposal (Circle Economy, 2018). Similar to the previous case, percentages will thus flow linearly from initial Business-As-Usual values to the potential final ones just mentioned, as shown in table 5.

Circular stage 2	***2025***	***2026***	***2027***	***2028***	***2029***	***2030***
Reusable	**0,512**	**0,512**	**0,512**	**0,512**	**0,512**	**0,512**
Downcycle	0,506	0,465	0,424	0,383	0,341	0,300
Dispose	0,484	0,407	0,330	0,253	0,177	0,100
Closed loop	0,010	0,128	0,246	0,364	0,482	0,600

Table. 5 - Circular Stage 2 flows assumptions

Ultimately, Circular Stage 3 will include also models of waste prevention, such as eco-design principles and consumer consciousness raising initiatives. Consequently, overall volumes in circulation will be reduced. Moreover, for what regards reusable materials, is it assumed that principles of clothing longevity shall have a positive impact on durability and resellability. Reuse percentages are thus expected to rise at least till 60% which is the current performance level (HU). On the other side, the Interreg report mentioned above, also states that "Recycling solutions currently in development could increase the types of fibres/fibre blends that can be used in textile-to-textile recycling, so in the future a larger portion of what is being downcycled could potentially be diverted for high-value use." (Circle Economy, 2018). Accordingly, once all improvements in more sustainable, efficient and effective design, collection, sorting and recycling are deployed, as in Circular Stage 3, it shall be possible to drastically enhance closed-loop streams and shrink volumes to be disposed of. The development from initial Business-As-Usual values to the potential maximum outcomes is displayed in table 6.

Circular stage 3	***2025***	***2026***	***2027***	***2028***	***2029***	***2030***
Reusable	**0,512**	**0,530**	**0,547**	**0,565**	**0,582**	**0,600**
Downcycle	0,506	0,413	0,320	0,227	0,133	0,040
Dispose	0,484	0,389	0,294	0,199	0,105	0,010
Closed loop	0,010	0,198	0,386	0,574	0,762	0,950

Table. 6 - Circular Stage 3 flows assumptions

In conclusion, the objective will thus be to link these percentages presumably achieved through the differentiated incentive approach of the framework will also drive a higher environmental sustainability of the whole system.

4.3. FINANCIAL SUSTAINABILITY TEST

The purpose of this specific module of the validation process aims at verifying the economic preferability of closed-loop options rather than open-loop recycling, as well as the impact of possible value redistribution and economic sustainability enhancement outcomes produced by the gradual application of the novel framework proposed. In order to properly define and evaluate the diverse effects comprised, the test has been implemented across the hypothetical value chain constructed above. A separate analysis has thus been carried out for each of the actors, i.e. the fibre producer which acts also as recycler, the fabric producer, the retail brand (MUD Jeans) and finally the integrated collector and sorter. Furthermore, each analysis case differentiated into 4 diverse sub-studies relating to the 4 different scenarios investigated.

The evaluation process entailed the following steps:

1. ***Construction of basic Profit & Loss statements for each actor for each scenario, excluding financial management***: revenues and costs streams were thus drawn till the determination of EBITDA values

2. ***Determination of subsidies necessary for the integrated collector and sorter to achieve breakeven***: a simplification is here deployed due to the specific structure of the value chain build up. Given the fact that the fibre producer acts also as recycler it is complex to assess its financial unsustainability in regards to the recycling process. The subsidies will be thus provided only to the collector and sorter, which truly display a negative trend in net management costs

3. ***Allocation of fees for each scenario***: Once the total contribution necessary to cover the subsidies determined in step 2 is defined, it will be distributed among fibre producer, fabric producer and retail brand. In accordance with the necessity to individualise tax burdens (Massarutto, 2014) and the unbalanced innovation power among supply chain actors (Franco, 2017), a diversified distribution of fees weight is designed. Given the economic power, magnitude of impacts caused and relevance for widespread change, this retail stage will be charged with a percentage of the total fees, accounting for the majority of its pre-consumer and post-consumer waste flows. On the other side, given the role of sandwich spectators (Franco, 2017) of middle supply chain actors, the fabric producer will be charged with a percentage accounting for its own industrial excesses as well as a minority contribution to post-consumer waste flows. Finally, given the environmental impact caused and innovation power of fibre producers, this stage will be charged with a percentage accounting for its own industrial excesses as well as a slightly higher minority contribution to post-consumer waste flows. This structure of fees allocation shall provide a form of signalling discouraging brands from overproduction, unsustainable material mix and less eco-friendly design alternatives; fabric producers from applying hazardous finishing and coatings; fibre producer from exploiting non-renewable sources, unsustainable production processes or lower quality product features.

4. ***Provision of discounts for producers complying with Circular Stage 2 and Circular Stage 3***: Discounts are determined by compliance level in relation to sustainable and circular initiatives, measured through the KPI system. Generally, in order to simplify, the intrinsic role of these initiatives is to have companies handling their reverse flows and lightening the burden over the common end-of-life management infrastructure. In this implementation case,

discounts will be thus determined according to the savings in net costs for the integrated collector and sorter, achieved when all supply chain actors are compliant with the principles of a specific scenario. As a matter of fact, within industry current state there is still missing agreement on standardised measures for the proposed KPIs. Basically, for this test, they are thus comprised within the design of the different scenarios with related diverse flows' structure and are quantified indirectly.

5. ***Comparison of estimated NPV outcomes for each actor in each scenario in order to assess supply chain effects***: For each case of analysis an approximation of NPV will be calculated basing on EBITDA values, considering also fees, subsidies and discounts. This entails the hypothesis of resemblance of operational revenue and cost streams with the related financial flows. Furthermore, the discount rate is determined through the estimated cost of capital for the apparel market and is then exploited in all cases.

4.3.1. *Economic viability test – Findings*

Hence, the analysis will now go through each scenario, moving from downstream to upstream, studying first the situation of collector and sorter and last the one of the fibre producer. In particular, all results subsequently displayed are based on excel spreadsheets calculations, of which the main tables will be shown in Annex II.

BUSINESS-AS-USUAL SCENARIO

BAS Collector & Sorter

The Business-As-Usual scenario reflects the current state translated 5 years forwards and will thus need to depict the ever more stringent unbalance between reusable fraction and rising recovery costs, which slowly squeezes collectors and sorters on the edge of bankruptcy. The economic unsustainability of the end-of-life infrastructure is indeed what pushes the generation of such a fiscal framework. This stage of the value chain is seen as the key for the propelling of the whole closed-loop mechanism.

Foremost, the values to assess will be the quantities collected and the ones sorted, in relation to the small closed subsystem created with this hypothetical supply chain. The former mass is calculated with the following formula:

$$Quantity\ recovered = Brand\ outputs\ sold * l * w * m * \%Collection$$

Where l stands for the length of the denim fabric, w for the width, m for the average weight. The $'\%Collection'$ is determined by the complementary of the fraction not collected, which in turn corresponds to those flows sent to landfill or incinerators from indefinite sources, thus external to the collector. The resulting value will be:

$$\%Collection = 1 - (Globally\ disposed\ flows - \ Flows\ disposed\ by\ the\ collector)$$

Where $'Globally\ disposed\ flows'$ are assumed equal to the current state percentage of global flows destined to final disposal, thus 73% of the volumes produced according the report of 'A new textiles economy' (Foundation, 2017). On the other hand, $'Flows\ disposed\ by\ the\ collector'$ corresponds to the 'Disposal' stream

yearly development displayed in the previous chapter for each scenario. Beyond this, the mass of sorted materials is computed simply by multiplying the mass of recovered material by the percentage of sorting, which stood almost constant at 13% along the years for the analysed collector (HUMANA People To People, 2018). The rest of the volumes is resold directly as "original", thus as unsorted materials, or otherwise directly disposed of.

Moving on, once the volumes to be managed are defined, incomes are assessed according to the diverse streams making up the revenue model, as follows:

- *Second-hand clothing resale through a network of own branded shops*. This flow covers 26,17% of the sorted reusable materials and increases yearly with an estimated growth rate of 12,5%. The second-hand price averages between 5€ and 10€ per piece, with an annual increase in retail value of 2% (HUMANA People To People, 2018; Lehmann *et al.*, 2018). In addition, it is assumed that each kg contains an average of 4 clothing items (HU Interview)

- *Tropical mix exporting*. This flows actually do not earn money, because the vast majority of volumes is donated but it enhances the humanitarian nature and credibility of the company, thus pulling higher volumes of input used clothes pledged. It constitutes on average a 44,75% of reusable sorted materials (HUMANA People To People, 2018)

- *"Original" resale*. This quantity entails the mass of unsorted materials added to a percentage of sorted reusable materials, which remains after the first two options are separated. The "Original" price averages between 36 cents and 60 cents per kg, varying in accordance with the country of origin, with an annual increase in retail value of 2%. (HU) (Lehmann *et al.*, 2018)

- *Resale for Open-Loop recycling*. This flow reflects the percentage of sorted non-reusable materials that varies according to the 'Downcycling' stream yearly development displayed in the previous chapter. The price averages at 90 cents per kg, with an annual increase in retail value of 2% (Centro di Ricerca Economica e Sociale Occhio del Riciclone, 2013; Lehmann *et al.*, 2018)

- *Resale for Closed-Loop recycling*. This flow reflects the percentage of sorted non-reusable materials that varies according to the 'Closed loop' stream yearly development displayed in the previous chapter.

- The price averages between 5 cents and 10 cents per kg, with an annual increase in retail value of 2% (Circle Economy, 2018; Lehmann *et al.*, 2018)

For what regards the stream of goods analysed within this hypothetical supply chain, the income trends are shown in table 7.

BAS Revenues: Collector & Sorter	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Second-hand clothing resale	38.970 €	43.072 €	47.313 €	51.666 €	56.098 €	60.568 €
"Original" resale	16.674 €	18.034 €	19.502 €	21.089 €	22.802 €	24.653 €
Resale for Open-Loop recycling	113 €	123 €	134 €	146 €	159 €	173 €
Resale for Closed-Loop recycling	4 €	4 €	5 €	5 €	6 €	7 €

Table. 7 - BAS Revenues: Collector & Sorter

This table clearly demonstrates how the reusability factor tremendously impacts on income and how present recycling options may be considered negligible, practically obstructing the economic sustainability of sorters. The basis for a circular transition is thus undermined by an improper consideration or branding of second-hand clothing and an unfeasible reprocessing of single fibres. This stumbling blocks obscure the potential value behind the following of waste hierarchy principles and business models, stressing market conditions as well as rendering financing and systemic innovation ever more complex process, consistently letting the market stagnate and single players drown towards declining profitability.

Furthermore, the circumstances are worsened by the fact that operational costs tend to increase more than proportionally. The cost structure analysed in this implementation case is defined as follows:

- *Differentiated collection costs*. These are computed by considering 4 cents per collected kg (Luppi and Strada, 2019) and an additional 136,3 € for each additional ton collected in relation to management costs increase (Centro di Ricerca Economica e Sociale Occhio del Riciclone, 2013). Upon these the yearly inflation in energy prices has then been applied on top, with an estimated annual CAGR of 2,3% (Lehmann *et al.*, 2018)

- *Maximum bid*. Given the lack of future estimates, this metric is assumed constant, at a value of 10 cents per kg (Luppi and Strada, 2019)

- *Sorting costs*. These costs are computed basing on an estimated value of 5 cents per clothing piece sorted (HU Interview) and are then

incremented with an annual CAGR of 5% for what regards labour costs (Lehmann *et al.*, 2018)

- *Disposal costs*. This amount is compound according to trend estimates of "Special" waste categories as clothing and textiles, which increased expenses by 47% in 5 years (HU Interview)

- *Personnel costs*. These figures were estimated by analysing financial statements of the company of interest and finding it plausible to assume the mass of textiles managed as cost driver. Upon these values the yearly inflation in labour costs has then been applied on top, with an estimated annual CAGR of 5% (Lehmann *et al.*, 2018)

- *Leasing costs*. These figures were estimated by analysing financial statements of the company of interest and finding it plausible to assume the mass of textiles managed as cost driver. Upon these, an annual growth factor has been calculated applying the weighted average of inflation values for energy prices and labour, according to the relative relevance of these two price categories in the company cost sheets.

- *Other operating costs*. These figures comprise donations, contingent liabilities, various equipment, licenses and other management expenses. They were estimated by analysing financial statements of the company of interest and finding proportionality to revenues.

- *Service costs*. These figures comprise board of directors' compensations, insurances, maintenance, utilities and other services. They were estimated by analysing financial statements of the company of interest and finding proportionality to revenues.

Consequently, for what regards the stream of goods analysed within this hypothetical supply chain, the cost trends are shown in table 8.

BAS Operating Costs: Collector & Sorter	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Differentiated Collection costs	€ 22.396	€ 24.326	€ 26.413	€ 28.668	€ 31.105	€ 33.737
Maximum bid	€ 3.613	€ 3.847	€ 4.098	€ 4.364	€ 4.648	€ 4.950
Sorting	€ 1.174,12	€ 1.300,45	€ 1.438,25	€ 1.588,48	€ 1.752,16	€ 1.930,39
Disposal costs	€ 372,92	€ 452,91	€ 545,15	€ 651,06	€ 772,24	€ 910,46

Personnel costs	€ 11.359,74	€ 12.546,13	€ 13.838,84	€ 15.246,65	€ 16.779,06	€ 18.446,08
Leasing costs	€ 2.260,14	€ 2.019,47	€ 2.150,73	€ 2.290,54	€ 2.439,44	€ 2.598,00
Other operating costs	€ 3.447,18	€ 3.785,47	€ 4.139,16	€ 4.507,15	€ 4.887,95	€ 5.279,61
Services	€ 19.164,82	€ 21.462,49	€ 23.923,71	€ 26.546,99	€ 29.328,24	€ 32.259,73

Table. 8 - BAS Operating Costs: Collector & Sorter

Generally, it is noticeable how the predominant costs categories related to the burdens of recollection operations and human labour significance weight over the financial situation of collectors and sorters.

In these regards, it is possible to foresee the worsening of profitability measures along the years, as shown by the substantial decline in EBITDA shown in Figure 35.

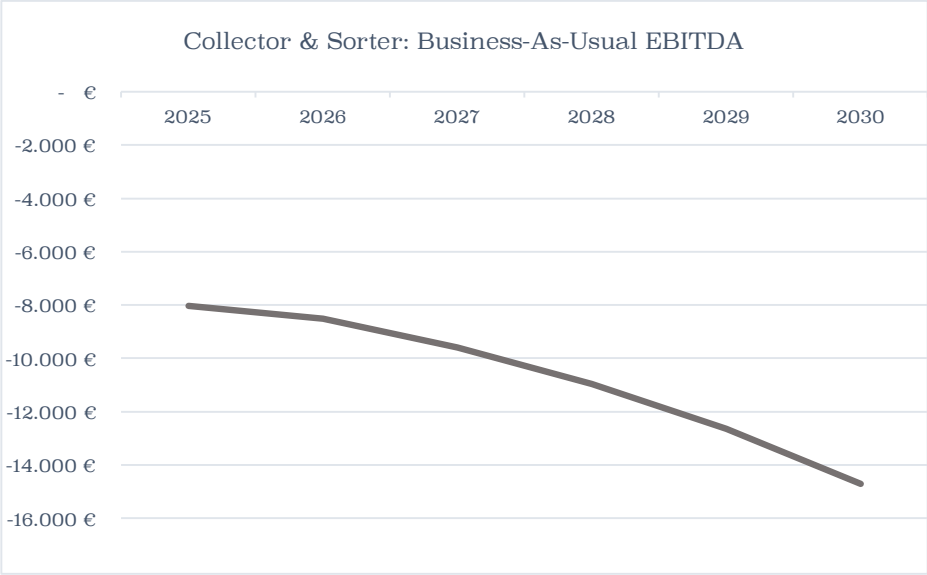

Figure. 35 - Collector & Sorter: Business-As-Usual EBITDA

BAS Retail brand: MUD Jeans

Moving further upstream, the situation of the retail brand shall be analysed thoroughly as well. The related Business-As-Usual scenario shows a growing market demand but this is also eroded by hurdles of rising operational costs, in particular for what regards production input costs and most of all burdensome disposal costs.

Quantities demanded are calculated according to the volumes objective expressed in MUD Jeans' interview, for what regards the efficient scale to achieve for the supply of inputs (MUD Interview). Upon this measure the estimated CAGR of the global denim market is applied on top (The Textile Magazine, 2016). Quantities produced are then calculated according to global estimates of overproduction. Accordingly, given the need to reflect a more generalizable current state of the fashion industry, the revenue streams will reflect only traditional sales both at full price and at discounted price. Indeed, as already mentioned, in global terms surplus stock is estimated as much as 30% of overall production, remaining blocked in the form of sample stocks, unsold batches or returned items. Yet another 30% only leaves the shops with discount (Ben *et al.*, 2010; Matevosyan, 2016). The measure of the price cut is assumed equal to the average discount on clothing during sales and is applied to the full price (Statista, 2017). Specifically, the original price is taken from the most used current price of women jeans on the website (MUD Jeans, 2020b), on which an annual increase of 2% in retail value is applied (Lehmann *et al.*, 2018).

Hence, the following Table 9 shows the trends of these two revenue streams.

BAS Revenues: Retail Brand	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Full price sales	€ 2.685.126	€ 2.911.635	€ 3.156.266	€ 3.420.410	€ 3.705.571	€ 4.013.308
Discounted price sales	€ 1.540.591	€ 1.670.551	€ 1.810.907	€ 1.962.460	€ 2.126.072	€ 2.302.636

Table. 9 - BAS Revenues: Retail Brand

On the other hand, the cost structure has been constructed diversifying among the following cost categories:

- *Textile inputs costs*. Basing on the prices set by the fabric manufacturer and multiplying the quantity produced with a unit of measure adjusting factor.

- *Total production costs*. These amounts are computed according to the estimation that fabric cost constitutes on average 60% to 70% of the total garment making cost (Fibre2Fashion, 2013)

- *Disposal costs*. These values are computed basing on the amount of overproduction and the estimation of disposal prices for "Special" waste typologies, already calculated for the collector and sorter

- *Selling, general and administrative costs*. These figures are estimated by analysing financial statements of the company of interest and finding proportionality of 40% to revenues. Upon these, an annual growth factor has been calculated applying the weighted average of inflation values for energy prices and labour, according to the relative relevance of these two price categories in the company cost sheets.

Consequently, for what regards the stream of goods analysed within this hypothetical supply chain, the operating cost trends are shown in table 10.

BAS Operating Costs: Retail Brand	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Textile input costs	€ 946.000	€ 1.025.801	€ 1.111.987	€ 1.205.048	€ 1.305.513	€ 1.413.932
Total Production costs	€ 1.576.667	€ 1.709.668	€ 1.853.311	€ 2.008.413	€ 2.175.856	€ 2.356.554
Disposal costs	€ 4.684	€ 5.231	€ 5.828	€ 6.482	€ 7.195	€ 7.974
Selling, general, administrative costs	€ 1.991.846	€ 2.225.272	€ 2.483.130	€ 2.767.769	€ 3.081.751	€ 3.427.827

Table. 10 - BAS Operating Costs: Retail Brand

Among the factors causing the decline in profitability assessed in the 'Pulse of the Fashion Industry' report (Lehmann *et al.*, 2018), the ones impacting most in these circumstances are the rising non-renewable raw materials prices, the higher exposure to supply chain shocks, as well as stricter and more expensive regulatory schemes, especially for end-of-waste resource management. As a result, it is possible to foresee the worsening of profitability measures along the years, as shown by the appreciable decline in EBITDA shown in Figure 36.

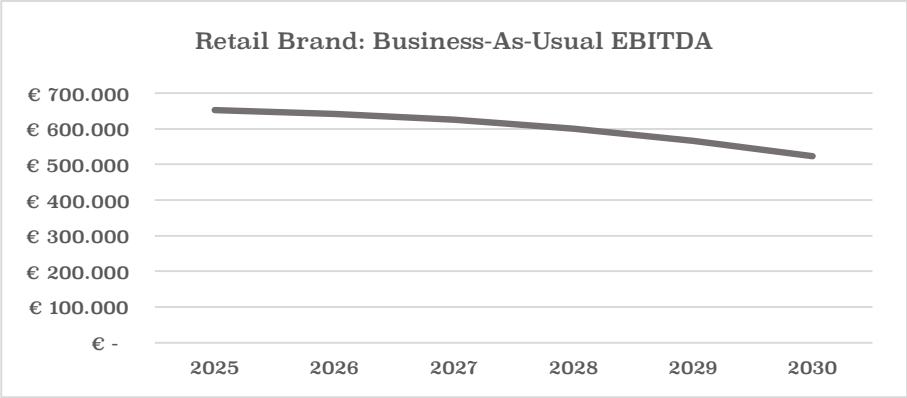

Figure. 36 - Retail Brand: Business-As-Usual EBITDA

Although the assumptions made may distort the quantitative measures of financial streams, the qualitative trend is apparent. This demonstrates how the ideal of pushing towards rising volumes, does not organically entail a good tactic for economic growth. Without long-term strategic business models, companies will tend to spend indeed a lot more for each unit produced and wills not able to extract the maximum value out of it, thus weakening their business performance and future persistency.

BAS Fabric Producer: Denim Mill

The situation of the fabric producer resembles the case exposed before, thus squeezed between rising competition and ever more burdensome labour and textile input costs. Here the quantities demanded will correspond to the ones produced by the brand, adjusted with coherent unit of measure factors. For what regards the quantities produced, the global assumption of 12% losses in production is applied, accounting for offcuts and overstock liquidation (Foundation, 2017).

On the side of income, the revenue stream analysed will be only one, i.e. the denim fabric type destined to the production of jeans for the specific retail brand. This is thus based on the overall quantity demanded and on a reference price for high quality denim[v]. Upon this the annual increase of 2% in retail value is then applied on top (Lehmann *et al.*, 2018). The overall results are shown in table 11.

BAS Revenues: Fabric Producer	2025	2026	2027	2028	2029	2030
Total revenues	€ 946.000	€ 1.025.801	€ 1.111.987	€ 1.205.048	€ 1.305.513	€ 1.413.932

Table. 11 - BAS Revenues: Fabric Producer

On the side of cost, the different categories assessed are the following:

- *Textile input costs*. This typology will be subdivided into two streams, in order to account on one hand for virgin material inputs and other for recycled material inputs. The formers include 67% of virgin cotton, 16% of virgin viscose, 14% of virgin polyester and 2% of virgin elastane, relating to the total amount of fabric required. The related prices base on average high quality fibres' market reference prices[vi][vii][viii], as well as on the prices set by the fibre producer if the analysed hypothetical supply chain for what regards viscose. In combination to this, the only recycled input will be 1% of recycled viscose relating to the total amount of fabric required, given the reliability of this specific process of the specific fibre producer, which already proved to be economically and environmentally viable.

- *Total production cost*s. These amounts are computed according to the estimation that fibre costs for the shell fabric and for the pocketing fabric together constitute 68,89% of the total garment making cost (Mohibullah *et al.*, 2019)

- *Textile fibres disposal cost*. These figures are estimated basing on current unitary costs derived from an interview with the fabric producer, on which the annual growth rate of "Special" waste typologies is applied.

- *Leasing costs*. These figures are estimated by analysing financial statements of the company of interest and finding an almost constant proportionality of 13% to revenues.

- *Personnel costs*. These figures are estimated by analysing financial statements of the company of interest and finding an even proportionality of 25% to revenues. Upon these values the yearly inflation in labour costs has then been applied on top, with an estimated annual CAGR of 5% (Lehmann *et al.*, 2018)

Consequently, for what regards the stream of goods analysed within this hypothetical supply chain, the operating cost trends are shown in table x.

BAS Operating costs: Fabric Producer	2025	2026	2027	2028	2029	2030
Textile input costs	€ 257.805	€ 281.024	€ 306.162	€ 333.370	€ 362.810	€ 394.650
Virgin material costs	€ 254.095	€ 277.260	€ 302.364	€ 329.563	€ 359.021	€ 390.911
Recycled materials costs	€ 3.710	€ 3.764	€ 3.798	€ 3.807	€ 3.789	€ 3.738
Total Production costs	€ 374.230	€ 407.934	€ 444.425	€ 483.920	€ 526.655	€ 572.874
Textile Fibres Disposal costs	€ 1.926	€ 2.131	€ 2.355	€ 2.599	€ 2.865	€ 3.154
Leasing costs	€ 118.785	€ 128.806	€ 139.628	€ 151.313	€ 163.928	€ 177.542
Personnel costs	€ 325.592	€ 366.134	€ 411.071	€ 460.834	€ 515.896	€ 576.763

Table. 12 - BAS Operating costs: Fabric Producer

In respect to this and in consistency with the results obtained for the other players, it is possible to understand the effects of low power of middle supply chain actors, which are dominated by both upstream and downstream players (Franco, 2017). The decline in EBITDA is shown in figure 37.

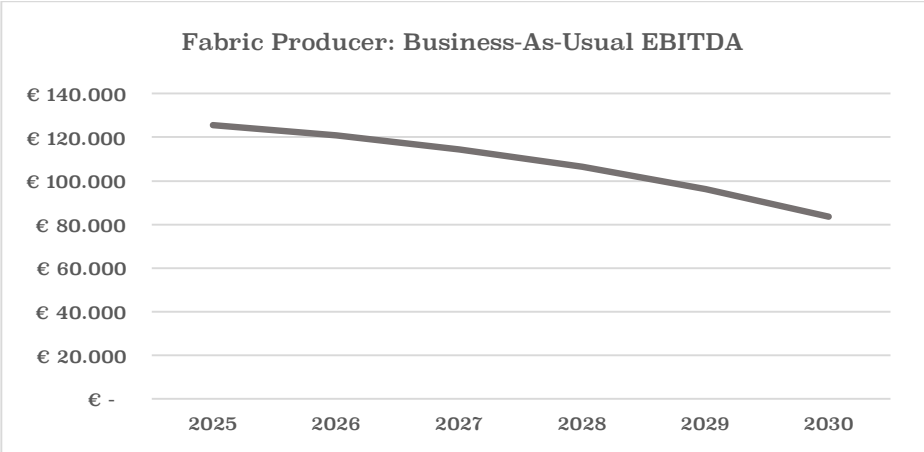

Figure. 37 - Fabric Producer: Business-As-Usual EBITDA

BAS Fibre Producer

Finally, the evaluation shall assess the results for the first step of the supply chain, which is consistently also the last within the cycle in relation to its additional role as recycler. Being farther away from end consumer demand patterns and holding a fair share of bargaining power, the negative effects will be milder but still appreciable. Commodity prices inflation challenge indeed a business model based on high volumes and cost efficiency.

In relation to this high efficiency, the volumes produced will exceed volumes demanded only by 1%. As a matter of fact, the company of interest already applies significant process optimisation and circular economy principles for what regards resource management. Almost any excess is transformed into alternative closed-loop inputs for production processes or into new products to sell in secondary markets (Interview 1). On the other hand, for the implementation case of this hypothetical supply chain constructed, the volumes demanded will be calculated directly basing on the quantities to be produced by the denim mill, adjusted with coherent unit of measure factors.

The streams of revenues will be two, relating both to the role of traditional viscose producer as also to the role of recycler, even if the latter represents a negligible portion in the Business-As-Usual scenario. For the first stream, a reference price[ix] of quality viscose will be considered and adapted by applying the growth rate of energy prices (Lehmann *et al.*, 2018). For the second stream, an assumption extracted from the interview with Lenzing has been exploited. Specifically: "At the moment, recycled raw materials are at least 50% costlier than virgin. We believe it will go down: for example, in recycled polyester they started with premiums of 50% and now they are down to 10% or maybe even nearer to cost. So I think it will go down but still it depends, I believe they will always be at least equally expensive if not even more than traditional ones, still in 5 years. Particularly economies of scale can play a relevant role, I would say from 10.000 tons to a 100.000 we talk about 50% cost reduction, thanks to the economies of scale." (LE) Hence, recycled material prices are assumed to be 50% costlier in the first year and to shrink linearly during the years of analysis, reaching price parity.

In accordance, the income structure is shown in table 13.

BAS Revenues: Fibre Producer	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Virgin viscose sales	€ 41.629	€ 45.249	€ 49.164	€ 53.397	€ 57.973	€ 62.918
Recycled viscose sales	€ 631	€ 640	€ 646	€ 647	€ 644	€ 636

Table. 13 - BAS Revenues: Fibre Producer

As noticeable, the magnitude of figures is quite restricted. This links to the fact that fibre producers need to work on high volumes and optimal productivity. Consistently, on the side of expenses, the basic operational cost structure evaluated is the following:

- *Cost of materials and other purchased services*. This category entails the primary inputs consumed as wood pulp and key chemicals as well as the consumption of energy. The related figures were estimated by analysing financial statements of the company of interest and finding it plausible to assume the tons produced as cost driver. Upon these, an annual growth factor has been calculated applying the weighted average of inflation values for energy prices and labour, according to the relative relevance of these two price categories in the company cost sheets (Lehmann *et al.*, 2018).

- *Personnel costs*. These figures were estimated by analysing financial statements of the company of interest and finding it plausible to assume the tons produced as cost driver. Upon these values the yearly inflation in labour costs has then been applied on top, with an estimated annual CAGR of 5% (Lehmann *et al.*, 2018)

- *Other operating expenses*. This category entails selling, certification and disposal costs, in addition to other additional factors. These values were estimated by analysing financial statements of the company of interest and finding a quite constant proportionality of 12% to revenues.

Accordingly, for what regards the stream of goods analysed within this hypothetical supply chain, the operating cost trends are shown in table 14.

BAS Operating Costs: Fibre Producer	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Cost of material and other purchased services	19.729 €	21.714 €	23.874 €	26.223 €	28.776 €	31.551 €
Personnel Costs	8.969 €	10.113 €	11.384 €	12.793 €	14.354 €	16.081 €
Other Operating expenses	5.099 €	5.537 €	6.010 €	6.521 €	7.073 €	7.668 €

Table. 14 - BAS Operating Costs: Fibre Producer

As apparent the two most impacting cost typologies are related to production inputs and labour costs, which thus hamper the efficiency and drive down profitability. Still, the uplift in volumes, enabled by the growth of the final denim jeans market, slightly mitigates the decline in EBITDA, as shown in Figure 38.

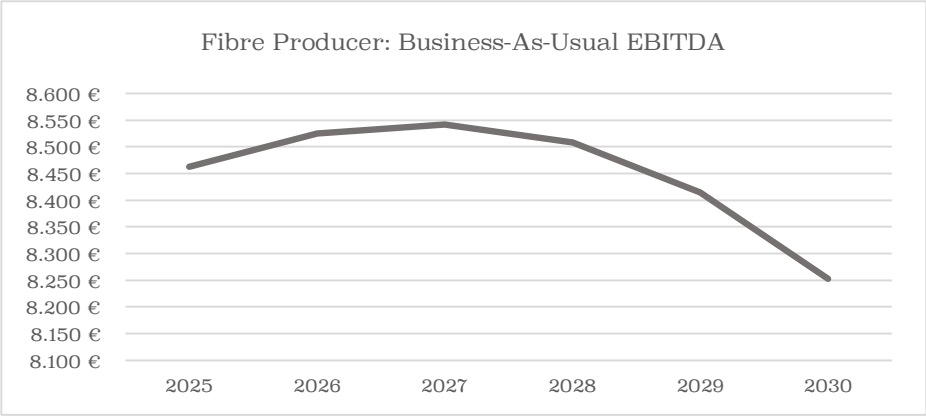

Figure. 38 - Fibre Producer: Business-As-Usual EBITDA

In conclusion, the results obtained for the Business-As-Usual scenario, i.e. the most foreseeable from the current state if no driving actions are taken, reveals substantially negative economic developments of the whole supply chain, with more burdensome effects on the end-of-life management stage, as anticipated in the previous analysis of the state of the art and of the state of practice. Outcomes will be further discussed in section x, aiming at a constructive comparison among the diverse scenarios outcomes, assessing the effect on each value chain player.

CIRCULAR STAGE 1 SCENARIO

As stated above, the Circular Stage 1 is the first step and building block in the implementation of the proposed framework. This comprises the redistribution of value along the supply chain and subsidization of recollection infrastructure scaling up, rendering investments in sorting and recycling technologies economically viable and leaning up the whole reverse supply chain, for the sake of higher convenience of closed-loop products and waste disposal reduction across the whole industry. This systemic transition is enabled by the widespread exploitation of blockchain for the traceability of flows and

payments, while also facilitating the addressing of waste stream towards the best suited destinations, in accordance with the European waste hierarchy.

In particular, for the implementation case evaluation, blockchain related costs are estimated basing on requirements as transaction volume, transaction size, node hosting method and consensus protocol (EY, 2019). Furthermore, given the homogeneity of technicalities required among circular scenarios, apart from an increasing volume of transactions, as well as given the unavailability of larger amounts of quantitative data to study, CAPEX and OPEX for blockchain technology implementation will be assumed as constant across the three stages of construction of the proposed framework. Specifically, in order to tailor the estimates onto the hypothetical supply chain assessed, the 'Blockchain App Development Calculator' provided by LeewayHertz[x] has been exploited. The specific definition criteria selected are the following:

- New blockchain product creation
- Private blockchain
- Financial transaction handling requirement
- Minor computation in the cloud requirement (in relation to IoT data capturing)
- Inclusion of administrator interfaces and mobile app interfaces
- Normal speed of development
- 6 types of users interfacing with the platform (fibre producer, fabric producer, brand, collector/sorter, final customer, regulator)

The private blockchain model has been chosen in opposition to the public blockchain option, because the structure demanded for the implementation of the framework proposed will be a consortium largely based on a permissioned network of full nodes, providing then limited access to permissionless end users. As mentioned in the relative section within the literature review, permissioned blockchain will comprise higher fixed costs but then offer greater convenience in costs per transaction.

Results refer to CAPEX and OPEX per single organisation. Detailed expenses will be thus displayed in the cost structure deployed for each of the following scenarios and allocated according to revenues earned for the specific flows comprised in the implementation case in relation to total organisation revenues. This assumption comprises a link between revenues factors and blockchain requirements of transaction volume. The transaction size, node hosting method and consensus protocol remain instead constant in the allocation. Size of

transactions is estimated medium, given the need of application of several smart contracts to execute agreements based on programmable conditions (EY, 2019). The node hosting method selected is cloud-based, given the prerequisite to facilitate implementation in a very widespread and diverse network. Finally, the consensus protocol selected is the proof-of-stake, for the sake of energy saving and 51% attack tolerance, as mentioned before.

CS1 Collector & Sorter

End-of-life management plays a dramatically critical role in this first step of implementation of the product stewardship features of the model. Value redistribution across the direct supply chain, shall spur a concrete revolution in volumes and processes of the reverse supply chain. The exploitation of economies of scale, flows logistical optimisation and facilitation of network relationships as well as innovation investments, is expected to drive the convenience of closed-loop products. Upon this, the application of the polluter-pays-principle is expected to increase awareness across the industry stakeholders and modify production patterns, in order to alter also waste creation patterns. In accordance, prices and costs of the end-of-life operators need to align with waste hierarchy principles, aiming at the true achievement of industry wide circular targets.

Consequently, collectors will impact to a much greater extent on the recovery both of post-consumer waste volume as well as on pre-consumer excess streams. Collected quantities in this specific implementation case supply chain, are thus assumed to cover the majority of jeans sold to end-consumers and the totality of industrial textile by-products from the stages before, complying with the following formula:

$$\begin{aligned} Quantity\ recovered \\ &= (Brand\ outputs\ sold * 0{,}9 + (Brand\ outputs\ produced \\ &- Brand\ outputs\ sold)) * l * w * m \\ &+ (Fabric\ outputs\ produced - Fabric\ outputs\ sold) * w * m \\ &+ (Fibre\ outputs\ produced - Fibre\ outputs\ sold) * 1000kg/t \end{aligned}$$

For what regards sorting a novel differentiation shall be introduced. In combination with the subsidisation of end-of-life infrastructure scale up, automatic sorting technologies development shall be incentivised in order to lean up the whole process, provide a pre-screening before manual sorting and minimize quantities sent to landfill. NIR scanning technologies, as Fibersort, will be thus exploited in this implementation case to split flows of materials with potential for closed-loop recycling resale from flows to sell as “original” to third parties. In respect to this, quantities sent to closed-loop recycling will be calculated according to the following formula:

$$Closed\ Loop\ Quantity = Quantity\ recovered * (1 - \%Reuse) * \%Closed\ Loop$$

On the other side, volumes processed via manual sorting in search for the reusable fraction are assumed to maintain a constant relative level, throughout all scenarios.

Revenues streams resemble the ones discussed in 'BAS Collector & Sorter'. The only difference lies in the price settable for materials sent to closed-loop recycling. As mentioned in the interview with a game changer of chemical recycling processes, the exchange of feedstock for recyclers still represent an inexistent market. As consequence of the subsidisation and optimisation of the reverse supply chain, increased business interest will be drawn towards these markets and once the industry will understand the possibility to make profitability on these feedstock materials the prices are expected to rise. Specifically, the objective is to facilitate the compliance with the waste hierarchy and thus the favouring of closed-loops over "original" resale with loss of control and traceability. In these regards, the collector is assumed to higher closed-loop resale prices above the ones of "original" resale, with a premium of 20 cents/kg accounting for the additional costs of sorting to bear for the management of these flows (HU).

Accordingly, the income structure will be shown in table 15.

CS1 Revenues: Collector & Sorter	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Second-hand clothing resale	69.338 €	80.954 €	88.925 €	97.106 €	105.435 €	113.836 €
"Original" resale	29.502 €	33.219 €	35.352 €	37.556 €	39.825 €	42.475 €
Resale for Open-Loop recycling	204 €	245 €	277 €	313 €	353 €	472 €
Resale for Closed-Loop recycling	228 €	925 €	1.779 €	2.828 €	4.102 €	5.201 €

Table. 15 - CS1 Revenues: Collector & Sorter

Comprehensive results thus unfold how a more accurate and efficient preliminary sorting process may actually prove the growing validity of the revenue stream of materials destined for closed-loop recycling.

On the other hand, operational expenses resemble the ones discussed in 'BAS Collector & Sorter'. The only cost source to add here is the amount of OPEX related to the implementation of blockchain. As abovementioned, total related cost of ownership has been assessed through the 'Blockchain App Development

Calculator' provided by LeewayHertz[xi]. For what regards the OPEX, the total outcomes comprise a third party monthly fee of 2550$, which will be then allocated for the specific stream of goods analysed.

Generally, the overall outlook is shown in table 16.

CS1 Operating Costs: Collector & Sorter	***2025***	***2026***	***2027***	***2028***	***2029***	***2030***
Differentiated Collection costs	43.443 €	50.361 €	55.220 €	60.498 €	66.228 €	72.448 €
Maximum bid	6.428 €	7.231 €	7.701 €	8.202 €	8.735 €	9.303 €
Sorting	2.089 €	2.444 €	2.703 €	2.986 €	3.293 €	3.628 €
Disposal costs	650 €	763 €	841 €	921 €	1.002 €	829 €
Personnel costs	20.212 €	23.580 €	26.010 €	28.656 €	31.536 €	34.669 €
Leasing costs	4.021 €	4.670 €	5.128 €	5.627 €	6.169 €	6.757 €
Other operating costs	6.137 €	7.131 €	7.810 €	8.519 €	9.256 €	10.014 €
Services	34.120 €	40.429 €	45.141 €	50.178 €	55.535 €	61.188 €
Blockchain OPEX	€ 331,49	€ 331,49	€ 331,49	€ 331,49	€ 331,49	€ 331,49

Table. 16 - CS1 Operating Costs: Collector & Sorter

As a consequence of greater volumes to manage and additional operating expenses, the negative EBITDA trend is shown in Figure 39.

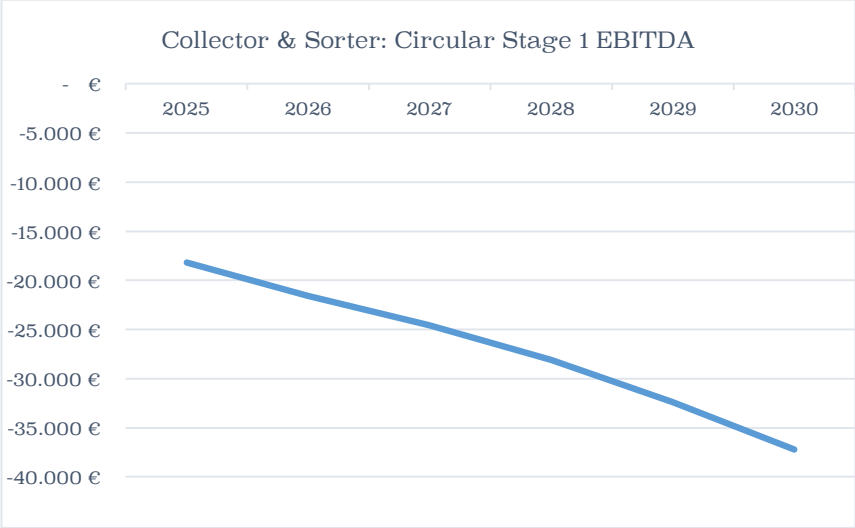

Figure. 39 - Collector & Sorter: Circular Stage 1 EBITDA

Beyond this, the fundamental variation in respect to Business-As-Usual lies in the investments which are targets of the subsidisation. In particular, it is necessary to allocate to this hypothetical supply chain case study the capital expenses for the implementation of Fibersort technology as well blockchain architecture. The former has an estimated investment cost of 600000€. One machinery for each collector is assumed and therefore the whole cost is allocated measuring the quantities collected in this specific case against the overall volumes recovered by the whole infrastructure of this specific collector, basing on data of related sustainability and financial reports. The latter investment measure, assessed through LeewayHertz[xii], is composed by 119000$ of development costs and 12920$ of additional consulting, visual and technical design. The overall figure is then again allocated for the specific stream of goods analysed, resulting in global investment for the first year of analysis of € 2.883,51.

These figures are exploited for the determination of total subsidies, which correspond to the net end-of-life management costs, as shown in table x. Additional, overall findings will be used later on to compute the NPV for each actor and each scenario in order to provide a constructive discussion of value enhancement and redistribution effects.

	2025	**2026**	**2027**	**2028**	**2029**	**2030**
CS1 Subsidies to Collector & Sorter	€ 21.043	€ 21.597	€ 24.554	€ 28.115	€ 32.370	€ 37.184

Table. 17 - CS1 Subsidies to Collector & Sorter

Aggregate amounts of capital required for the product stewardship scheme will be then split among supply chain producers through a tailored balancing approach. In accordance with the principles of allocation enounced above, fees shall reflect waste flows produced and responsibilities owned of each actor.

Hence, the retail brand shall own the major portion of fees, given the fact that it produces 88,33% of the mass of excesses recovered by the collector in this scenario and widely influences repercussions of environmental performances both upstream as also downstream. Still part of this impacts shall be beard by the fabric producer and by the fibre producer, given the impact of specific yarns and denim on durability, reusability and recyclability performances, thus providing a direct link explicating effects of diverse production alternatives and providing a form of signalling to all. In these regards, flows percentages shall be adjusted to transfer part of the responsibility for the waste produced at retail stage to the upstream stages.

Specifically, it is assumed that the fibre producer will be charged for the portion of own industrial excesses in addition to the 17% of an estimated 4% of the impacts related to the volumes of brand pre- and post-consumer waste flows.

The 17% refers to the percentage of viscose present in these pre- and post-consumer waste flows. The remaining 83% shall be charged to cotton, polyester and elastane producers, but is out of scope for this testing ground. Furthermore, it is likewise assumed that the fabric producer will be charged for the portion of own industrial excesses in addition to an estimated 1% of the impacts related to the volumes of brand pre- and post-consumer waste flows, given the lower impact of fabric production practices on durability, reusability and recyclability performances. Finally, as a result the brand will be charged of a fee proportional to the 95% of the 88,33% of the mass of excesses recovered by the collector.

CS1 Retail brand: MUD Jeans

Given the focus of Circular Stage 1 towards end-of-life management and closed-loop raw materials convenience, the retail stage is not tremendously impacted. Relevant to notice are the change in the material mix patterns, related increase in demand for circular-oriented products and the implementation of the blockchain architecture, assuring higher traceability, reliability and influence on stakeholders.

For what regards sales volumes, according to estimates retrieved from the interview with Lenzing, the perceived increase in demand for sustainable alternative products corresponded to annual rate of 6%. This metric will thus be applied to the overall denim market expansion measure considered for the Business-As-Usual scenario. As a matter of fact, it is widely acknowledged among journal articles and company reports, that the quest towards more sustainable and circular jeans production methods is the key trend and driving force for companies in the blue world (Denim Première Vision, 2019b).

Accordingly, revenues will slightly increase as shown in table 18.

CS1 Revenues: Retail Brand	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Revenues from traditional sales	2.685.126 €	3.081.168 €	3.347.074 €	3.635.942 €	3.949.704 €	4.290.576 €
Revenues from discounted sales	1.540.591 €	1.767.820 €	1.920.384 €	2.086.121 €	2.266.143 €	2.461.718 €

Table. 18 - CS1 Revenues: Retail Brand

On the side of operational costs, the company has to bear the additional third party fees for blockchain implementation, which corresponds in this case to the total amounts operational costs estimated, since the whole volume of flows of the organisation is analysed in this implementation case. OPEX structure will be thus shown in table 19.

CS1 Operating Costs: Retail Brand	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Textile input costs	946.000 €	1.083.594 €	1.174.636 €	1.272.940 €	1.379.048 €	1.493.583 €
Total Production costs	1.576.667 €	1.805.990 €	1.957.726 €	2.121.566 €	2.298.413 €	2.489.305 €
Disposal costs	4.684 €	5.525 €	6.157 €	6.847 €	7.600 €	8.423 €
Selling, general and administrative costs	1.991.846 €	2.354.841 €	2.633.245 €	2.942.175 €	3.284.785 €	3.664.645 €
Blockchain OPEX	27540 €	27540 €	27540 €	27540 €	27540 €	27540 €

Table. 19 - CS1 Operating Costs: Retail Brand

Consequently, the EBITDA trend still follow a declining function but offers slightly higher absolute profitability levels, as shown in Figure 40.

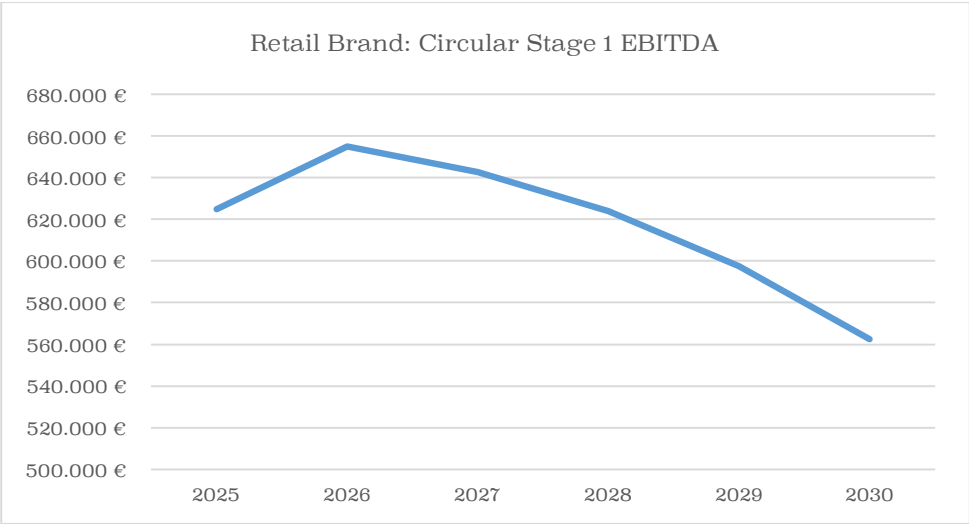

Figure. 40 - Retail Brand: Circular Stage 1 EBITDA

Furthermore, additional expenses are comprised in the design of this scenario. First of all, the implementation of blockchain requires a major initial investment, composed by 119000$ of development costs and 12920$ of additional consulting, visual and technical design. Further reasoning will be deployed in the discussion of net present values of each alternative scenario.

Secondarily, as abovementioned, this stage will bear product stewardship fees corresponding to 95% of the 88,33% of the comprehensive amount of subsidies need, causing the following expenses shown in table 20.

	2025	2026	2027	2028	2029	2030
CS1 PS Fees: Retail Brand	€ 17.659	€ 18.124	€ 20.605	€ 23.594	€ 27.164	€ 31.204

Table. 20 - CS1 PS Fees: Retail Brand

In summary, overall findings related to the first building block of the model appear to provide low reliability and effectiveness of sustainable incentives towards firms of this stage. More detailed conclusions will be carried out in the inclusive comparison that will be structured in the next section.

CS1 Fabric Producer

This supply chain stage will likewise face innovations for what regards demand, sourcing patterns and blockchain implementation. Sales volumes are retrieved from retail stage demand with adjusting units of measure factors and prices are kept equal to the Business-As-Usual scenario. Accordingly, revenues trend entails only a slight increase connected to higher quantities demanded, as shown in table 21.

CS1 Revenues: Fabric Producer	2025	2026	2027	2028	2029	2030
Total Revenues	946.000 €	1.083.594 €	1.174.636 €	1.272.940 €	1.379.048 €	1.493.583 €

Table. 21 - CS1 Revenues: Fabric Producer

On the other hand, expense streams increase more than proportionally in relation to OPEX, CAPEX and product stewardship fees. For what regards, the former typology, basic assumptions are equal to the Business-As-Usual scenario, apart from disposal costs which are assumed null, given the fact that the collector is estimated to collect the whole volume of industrial excesses of this stage and therefore these costs are translated into the fees to pay for the subsidisation of end-of-life management infrastructure. In addition, blockchain operational costs are equal to the ones beard by the other value chain players analysed and are again allocated according to the stream of goods analysed. The specific results are shown in table 22.

CS1 Operating Costs: Fabric Producer	2025	2026	2027	2028	2029	2030
Textile input costs	256.995 €	296.989 €	324.119 €	352.910 €	383.399 €	415.724 €
Price of virgin material	254.003 €	285.666 €	303.781 €	322.660 €	342.296 €	366.856 €
Price of recycled material	2.992 €	11.324 €	20.338 €	30.249 €	41.102 €	48.868 €
Total production costs	373.054 €	431.110 €	470.492 €	512.284 €	556.542 €	603.466 €
Disposal costs	- €	- €	- €	- €	- €	- €
Leasing costs	118.785 €	136.063 €	147.494 €	159.838 €	173.162 €	187.543 €
Personnel costs	325.592 €	386.762 €	434.230 €	486.797 €	544.954 €	609.254 €
Blockchain OPEX	395,12 €	395,12 €	395,12 €	395,12 €	395,12 €	395,12 €

Table. 22 - CS1 Operating Costs: Fabric Producer

The resulting trend in EBITDA is thus very similar to the Business-As-Usual scenario, as shown in Figure 41.

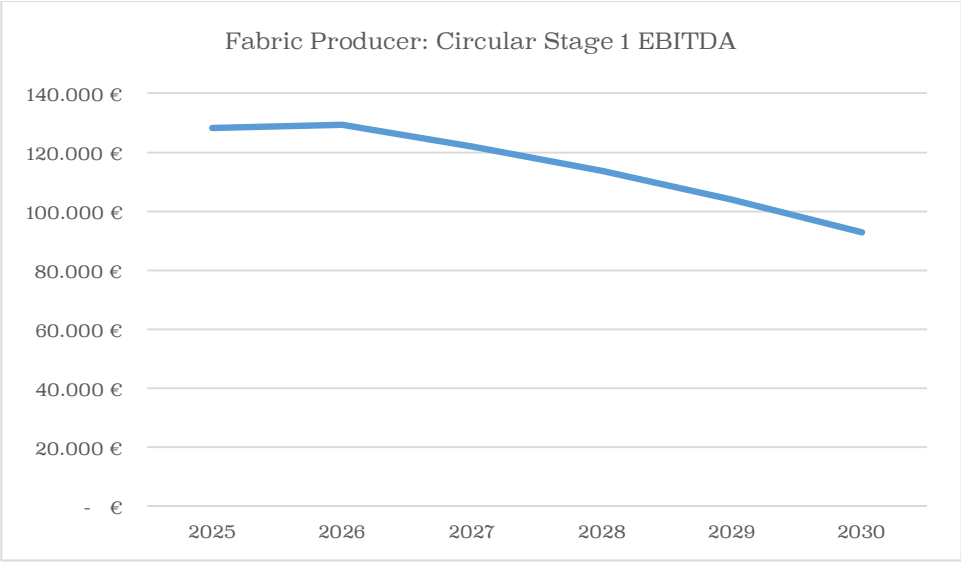

Figure. 41 - Fabric Producer: Circular Stage 1 EBITDA

Moreover, resembling the estimates made for the previous actors, blockchain CAPEX will cover development costs as well as additional consulting, visual and technical design, for a total investment of € 1.703,40 for this specific stage.

For what regards product stewardship scheme fees, the charge for the fabric producer will be of 100% of its own industrial excesses impacts and 1% of 88,33% of the impacts referred to the volumes of brand pre- and post-consumer waste flows, in relation to the totality of the subsidies to be transferred to the end of the supply chain. Resulting figures are shown in table 23.

	2025	2026	2027	2028	2029	2030
CS1 PS Fees: Fabric Producer	€ 2.602	€ 2.671	€ 3.037	€ 3.477	€ 4.003	€ 4.599

Table. 23 - CS1 PS Fees: Fabric Producer

CS1 Fibre Producer

Within the design of this scenario, the fibre producer is facing an initial growth in the demand for recycled materials, thus modifying production patterns. Accordingly, the two-fold revenue structure is shown in table 24.

CS1 Revenues: Fibre Producer	2025	2026	2027	2028	2029	2030
Virgin viscose sales	41.629 €	46.640 €	49.416 €	52.303 €	55.300 €	59.078 €
Recycled viscose sales	631 €	2.298 €	3.955 €	5.606 €	7.213 €	8.056 €

Table. 24 - CS1 Revenues: Fibre Producer

In respect to the operational costs structure, production figures will change accordingly to the two-fold products mix analysed. In particular, in correlation to VF estimates for the reduction of price premiums of recycled fibres during time as also for the decline in unit costs thanks to economies of scale potentially reached, the formula used to compute recycled viscose synthesis costs is the following:

$$Recycled\ prod.costs\ (i) = Qrecycled * c * (1{,}5 - 0{,}1 * i) * (1 + (6 + i) * w)$$

where i represents the year of analysis, corresponding to 0 in 2025 up till 5 in 2030. $Qrecycled$ accounts for the tons of recycled viscose to produce, computed

by multiplying the overall demand by the percentage of closed-loop flows defined in the general assumptions and finally applying the percentage of industrial excesses. $(1{,}5 - 0{,}1 * i)$ refers to the decrease in unit costs, which is assumed to follow a linear trend, embodying in the first year 50% higher costliness and reaching cost parity in the last year. $(1 + (6 + i) * w)$ is used to apply the annual growth of resource expenses, representing the weighted average of inflation values for energy prices and labour, according to the relative relevance of these two price categories in the company cost sheets (Lehmann et al., 2018). The financial statements analysed cover the years from 2015 till 2019, therefore the 6 accounts for the missing years till 2025. Moreover, 'Other Operating Costs' are reduced of the measure of 4,85% since the collector is estimated to collect the whole volume of industrial excesses of this stage and therefore these costs are translated into the fees to pay for the subsidisation of end-of-life management infrastructure. In addition, blockchain third party fees are an additional cost stream to bear, again in relation only to the flows assessed in this implementation case. Hence, the resulting structure is shown in table 25.

CS1 Operating Costs: Fibre Producer	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Virgin viscose production costs	19.531 €	21.440 €	23.011 €	24.656 €	26.373 €	28.488 €
Recycled viscose production costs	296 €	1.092 €	1.901 €	2.726 €	3.544 €	3.999 €
Personnel Costs	8.969 €	10.785 €	12.198 €	13.708 €	15.308 €	16.987 €
Other Operating expenses	4.844 €	5.609 €	6.117 €	6.638 €	7.165 €	7.695 €
Blockchain OPEX	143,12 €	143,12 €	143,12 €	143,12 €	143,12 €	143,12 €

Table. 25 - CS1 Operating Costs: Fibre Producer

As a result, the trend in EBITDA offers slightly higher profitability levels with a different curve shape in respect to the Business-As-Usual scenario, as shown in Figure 42.

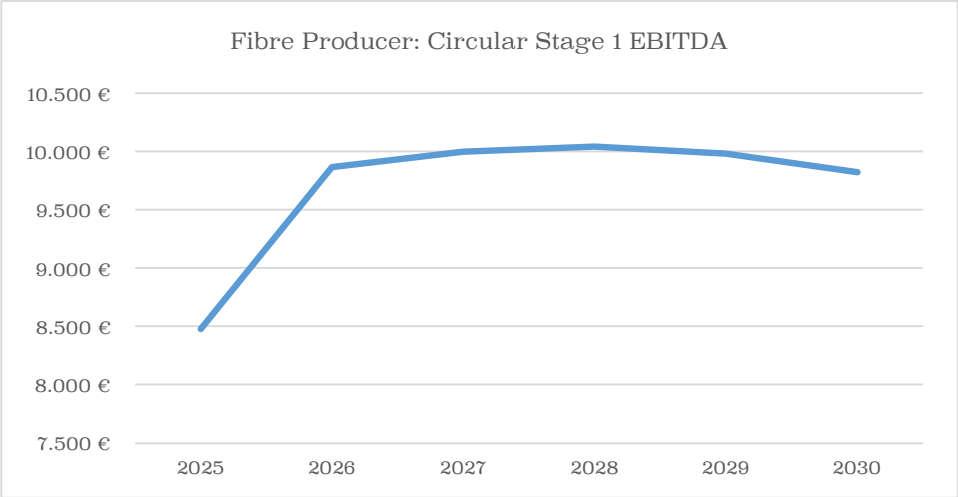

Figure. 42 - Fibre Producer: Circular Stage 1 EBITDA

On the side of investments, blockchain CAPEX in this case account for an investment of € 617,01 in relation limitedly to the volumes assessed in this evaluation test, covering development costs as well as additional consulting, visual and technical design.

For what regards product stewardship scheme fees, the charge for the fibric producer will be of 100% of its own industrial excesses impacts and 17% of 4% of 88,33% of the impacts referred to the volumes of brand pre- and post-consumer waste flows, in relation to the totality of the subsidies to be transferred to the end of the supply chain. Resulting figures are shown in table 26.

	2025	**2026**	**2027**	**2028**	**2029**	**2030**
CS1 PS Fees: Fibre Producer	€ 165	€ 169	€ 192	€ 220	€ 253	€ 291

Table. 26 - CS1 PS Fees: Fibre Producer

As anticipated, this scenario represents the second gradual implementation step of the proposed framework. In this case, supply chain actors are expected to start taking direct responsibility of their own value and waste streams, thus developing innovative operations management systems and beneficial business models. In particular, the analysed retail brand MUD Jeans adapt to this scenario perfectly, being a pioneer in the expansion of the rental market and in the promotion of reverse logistics and reconditioning used clothing.

In order to enable higher and more efficient value extraction from these novel business streams, blockchain technology will provide the digital layer to improve rewarding processes, customer loyalty programs and customer support, also relating to the care of the garment and final recovery options.

The more producers own their flows and are incentivised to raise quality standards for the truly profitable implementation of rental and resale models, the less weight will remain over collectors and sorters, which will thus manage rest flows with a generally higher reusable fraction comprised.

CS2 Collector & Sorter

As mentioned, recovered volumes will slightly change within this scenario of analysis. The related formula (x) is based on the assumption that retailers will be able to recollect an average of 35% of apparel volumes, corresponding to the present performance of one of the pioneers in this field (Patagonia, 2020), leaving the remaining 65% to be managed within the boundaries of the common end-of-life infrastructure.

$$\begin{aligned} &Quantity\ recovered \\ &\quad = (Brand\ outputs\ sold * 0{,}65 + (Brand\ outputs\ produced \\ &\quad - Brand\ outputs\ sold)) * l * w * m \\ &\quad + (Fabric\ outputs\ produced - Fabric\ outputs\ sold) * w * m \\ &\quad + (Fibre\ outputs\ produced - Fibre\ outputs\ sold) * 1000kg/t \end{aligned}$$

All other assumptions are kept homologous to the ones considered in Circular Stage 1, generating the following revenues and operational costs structures, shown in table 27 and 28.

CS2 Revenues: Collector & Sorter	2025	2026	2027	2028	2029	2030
Second-hand clothing resale	50.728 €	61.211 €	69.519 €	78.522 €	88.214 €	98.575 €
"Original" resale	21.583 €	24.978 €	25.054 €	24.906 €	24.502 €	23.815 €
Resale for Open-Loop recycling	149 €	171 €	168 €	164 €	158 €	149 €
Resale for Closed-Loop recycling	167 €	2.578 €	5.324 €	8.447 €	11.963 €	15.884 €

Table. 27 - CS2 Revenues: Collector & Sorter

CS2 Operating costs: Collector & Sorter	2025	2026	2027	2028	2029	2030
Differentiated Collection costs	31.783 €	36.387 €	39.342 €	42.429 €	45.631 €	48.926 €
Maximum bid	4.703 €	5.225 €	5.487 €	5.752 €	6.018 €	6.283 €
Sorting	1.528 €	1.766 €	1.926 €	2.094 €	2.269 €	2.450 €
Disposal costs	476 €	466 €	416 €	349 €	266 €	163 €
Personnel costs	14.787 €	17.037 €	18.531 €	20.097 €	21.728 €	23.413 €
Leasing costs	2.942 €	3.374 €	3.654 €	3.946 €	4.250 €	4.563 €
Other operating costs	4.490 €	5.498 €	6.186 €	6.926 €	7.718 €	8.557 €
Services	24.962 €	31.173 €	35.755 €	40.796 €	46.306 €	52.288 €
Blockchain OPEX	267 €	267 €	267 €	267 €	267 €	267 €

Table. 28 - CS2 Operating costs: Collector & Sorter

As a result, the EBIT curve shows a positive and promising change in trend, as shown in chart 43.

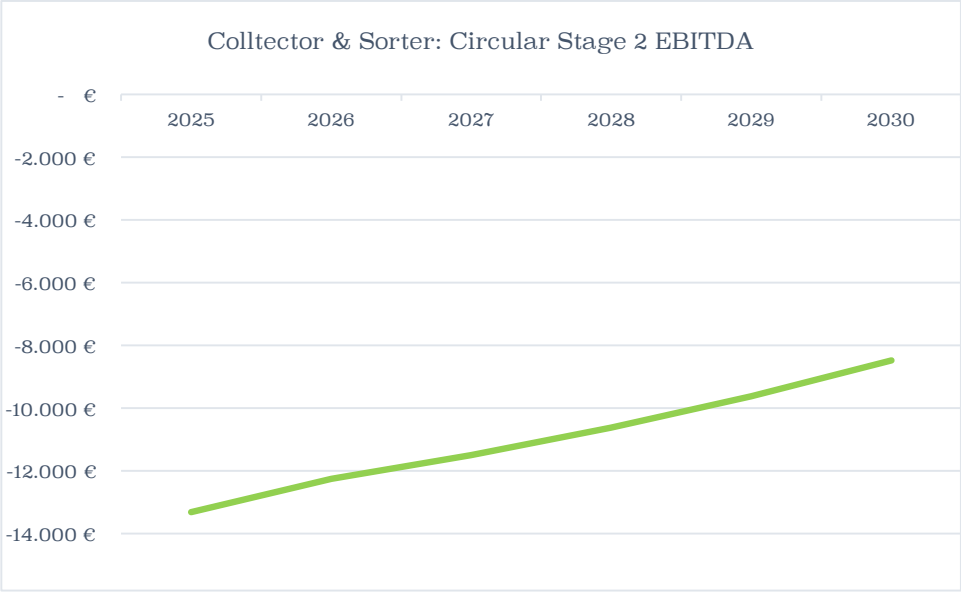

Figure. 43 - Colltector & Sorter: Circular Stage 2 EBITDA

For what regards investments, as before, Fibersort technology expenses of 600000€ are allocated measuring the quantities collected in this specific case against the overall volumes recovered by the whole infrastructure of this specific collector, basing on data of related sustainability and financial reports. On the other hand, blockchain expenses, composed by 119000$ of development costs and 12920$ of additional consulting, visual and technical design, are again allocated for the specific stream of goods analysed. The final global investment for the first year of analysis is of € 2.215,58.

Finally, in respect to all these end-of-life management expenses entailed for this scenario, total subsidies will be shown in table 29.

	2025	**2026**	**2027**	**2028**	**2029**	**2030**
CS2 Subsidies to Collector & Sorter	€ 15.525	€ 12.257	€ 11.498	€ 10.619	€ 9.616	€ 8.489

Table. 29 - CS2 Subsidies to Collector & Sorter

CS2 Retail Brand: MUD Jeans

As anticipated, since MUD Jeans puts great relevance in circular business models, revenue and cost patterns will change widely, in particular the former given the fact that it will be possible to extract more value from the same resources. Specifically, it is assumed that the structure of flows will resemble the current one for the first year of analysis and will then develop according to the CAGR estimates of the rental and resale market.

2025 will thus face a situation where 25% of sales volumes comes from the rental business model against 75% from the single sale business model, within which 1% represents the magnitude of the reconditioning & resale business model. Future relative significance of streams is driven by a CAGR of 10,76% for the rental market [xiii] and a CAGR of 9,72% (Thred Up, 2019). Future rental prices are computed basing on a membership fee of 29€ added to a monthly subscription of 7,5€. On the other hand, future reconditioned items prices are computed basing on the present price of 149€ per pair (MUD Jeans, 2020b). On top of all price an inflation rate of 2% is then applied, accounting for the growth in retail value (Lehmann *et al.*, 2018).

Consistently, revenues streams are displayed in table 30.

CS2 Revenues: Retail Brand	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Traditional sales	3.473.881 €	3.831.032 €	3.975.629 €	4.096.293 €	4.184.257 €	4.228.937 €
Recondition BM sales	63.038 €	76.385 €	87.109 €	98.646 €	110.767 €	123.085 €
Rental sales	1.269.230 €	1.712.727 €	2.028.235 €	2.434.480 €	2.921.189 €	3.504.238 €
Discounted sales	1.155.443 €	1.276.032 €	1.326.247 €	1.368.829 €	1.400.842 €	1.418.717 €
Closed-loop sales	705 €	1.449 €	2.262 €	3.196 €	4.267 €	5.490 €
Open-loop sales	521 €	538 €	519 €	493 €	459 €	415 €

Table. 30 - CS2 Revenues: Retail Brand

In respect to operational costs, two new categories are introduced. One will represent the cost for consumer loyalty in take-back systems, thus accounting for the volume of 10€ discounts granted for each pair of jeans returned. (Interview) The other is related to the whole reverse logistics management assuming costs comparable to the ones beard by the collector. As a result, the structure of OPEX will be the following, shown in table x:

CS2 Operating Costs: Retail Brand	2025	2026	2027	2028	2029	2030
Textile input costs	815.924 €	901.079 €	936.539 €	966.608 €	989.215 €	1.001.837 €
Total Production costs	1.359.874 €	1.501.798 €	1.560.898 €	1.611.013 €	1.648.691 €	1.669.728 €
Disposal costs	2.500 €	2.534 €	2.371 €	2.144 €	1.846 €	1.474 €
Selling, general and administrative costs	2.810.652 €	3.349.993 €	3.709.319 €	4.114.442 €	4.556.209 €	5.036.976 €
Discounting (rewards)	179.487 €	201.922 €	215.047 €	229.026 €	243.912 €	259.767 €
Reverse logistic costs	15.129 €	17.362 €	18.855 €	20.469 €	22.212 €	24.096 €
Blockchain OPEX	27.540 €	27.540 €	27.540 €	27.540 €	27.540 €	27.540 €

Table. 31 - CS2 Operating Costs: Retail Brand

As a result, the EBITDA curve faces an encouraging upturn in trend, as shown in Figure 44.

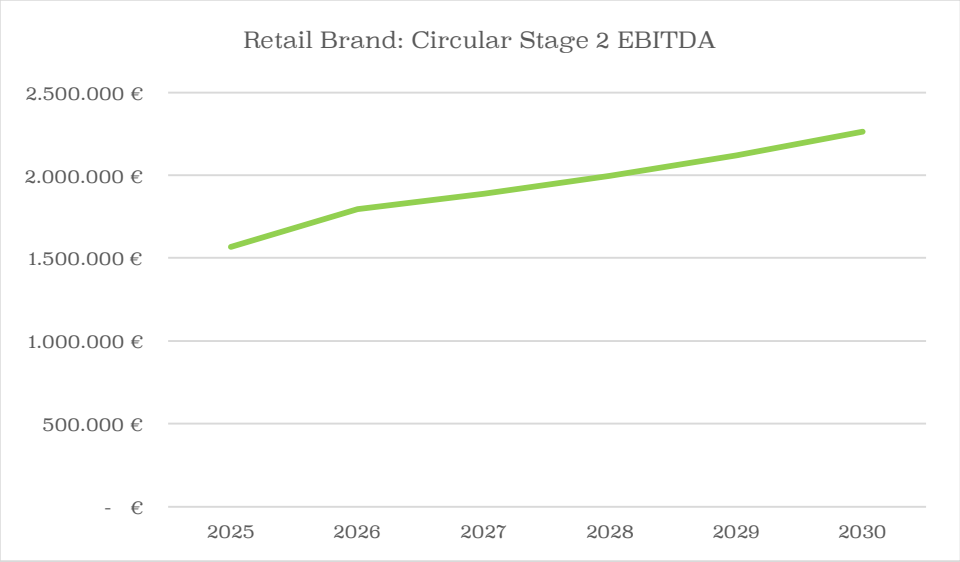

Figure. 44 - Retail Brand: Circular Stage 2 EBITDA

Beyond this, blockchain expenses are again beard for their totality in the case of the retail brand. CAPEX thus amount for € 118.728.

Finally, given the support for the circular management of flows, the burden of fees will be weaker, i.e. characterised by a small magnitude and by a decreasing trend, as shown in table 32.

	2025	2026	2027	2028	2029	2030
CS2 PS Fees: Retail Brand	€ 12.985	€ 10.284	€ 9.684	€ 8.980	€ 8.170	€ 7.252
CS2 Discounts (vs CS1)	4.673 €	7.839 €	10.922 €	14.614 €	18.993 €	23.952 €

Table. 32 - CS2 PS Fees & Discounts: Retail Brand

CS2 Fabric Producer

Due to the lower virgin production pulled by the retail stage, in connection to expanded downstream reuse of resources in form of rental and reconditioning, upstream stages will face diminishing volumes but may still hold or increase profitability levels by providing more innovative, qualitative and circular materials, which will be priced more.

In these regards, the fabric producer under analysis asserts to find the market possibility to put average price premiums of 15% for the products complying to the above mentioned characteristics. Additionally, on the side of costs, savings are possible referring to disposal expenses which are assumed null, given the fact that the collector is estimated to collect the whole volume of industrial excesses of this stage and therefore these costs are translated into the fees to pay for the subsidisation of end-of-life management infrastructure. Hence, revenue and operational cost structures are shown in tables 33 and y.

CS2 Revenues: Fabric Producer	2025	2026	2027	2028	2029	2030
Total revenues	815.924 €	901.079 €	936.539 €	966.608 €	989.215 €	1.001.837 €

Table. 33 - CS2 Revenues: Fabric Producer

CS2 Operating Costs: Fabric Producer	2025	2026	2027	2028	2029	2030
Textile input costs	192.746 €	217.290 €	228.385 €	236.271 €	240.290 €	239.779 €

Price of virgin material	190.502 €	186.464 €	168.580 €	147.606 €	123.711 €	97.262 €
Price of recycled material	2.244 €	30.826 €	59.805 €	88.664 €	116.580 €	142.518 €
Total production costs	279.790 €	315.418 €	331.524 €	342.971 €	348.806 €	348.064 €
Disposal costs	- €	- €	- €	- €	- €	- €
Leasing costs	102.452 €	113.145 €	117.597 €	121.373 €	124.212 €	125.797 €
Personnel costs	280.823 €	321.618 €	346.213 €	369.650 €	390.905 €	408.664 €
Blockchain OPEX	302 €	302 €	302 €	302 €	302 €	302 €

Table. 34 - CS2 Operating Costs: Fabric Producer

Accordingly, the resulting trend in operating margin is shown in Figure 45.

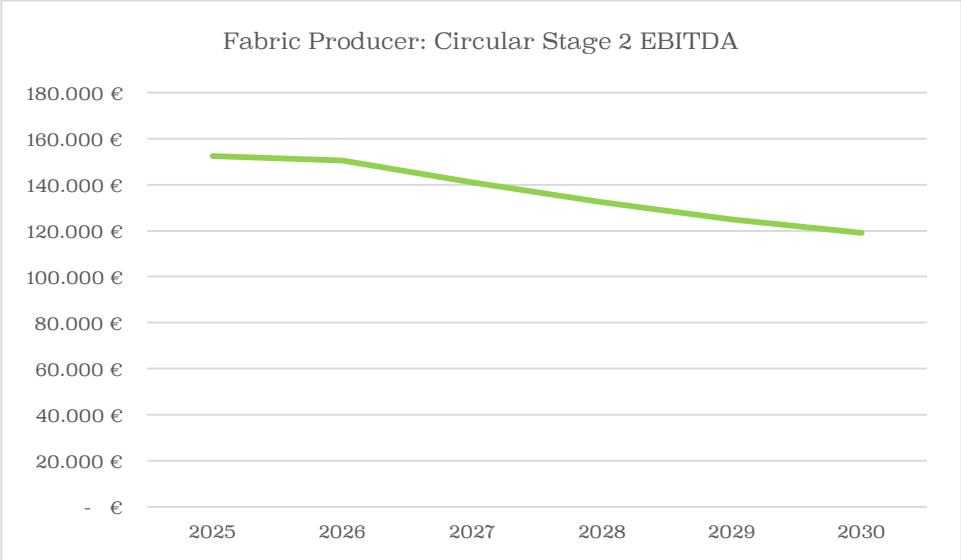

Figure. 45 - Fabric Producer: Circular Stage 2 EBITDA

Moreover, for what regards blockchain CAPEX, the total accounting for development costs and additional consulting, visual and technical design stays at € 1.300. On the other side, as anticipated, also the product stewardship fees' burden is reduced as shown in table 35.

	2025	2026	2027	2028	2029	2030
CS2 PS Fees: Fabric Producer	€ 1.964,38	€ 1.516,89	€ 1.386,85	€ 1.242,63	€ 1.085,69	€ 918,28
CS2 Discounts (vs CS1)	638 €	1.154 €	1.650 €	2.234 €	2.917 €	3.680 €

Table. 35 - CS2 PS Fees: Fabric Producer

CS2 Fibre Producer

Within this scenario, the fibre producer experiences a great growth in volumes for its recycled products, driven by expanded demand at retail stage and more efficient reverse supply chain infrastructure. Additionally, on the cost side, 'Other operating expenses' are reduced as in the previous scenario, in relation to the establishment of the product stewardship scheme. In accordance, revenues streams and operating costs are shown in tables 36 and 37.

CS2 Revenues: Fibre Producer	2025	2026	2027	2028	2029	2030
Virgin viscose sales	€ 31.222	€ 30.443	€ 27.423	€ 23.927	€ 19.986	€ 15.663
Recycled viscose sales	473 €	6.256 €	11.631 €	16.433 €	20.457 €	23.494 €

Table. 36 - CS2 Revenues: Fibre Producer

CS2 Operating Costs: Fibre Producer	2025	2026	2027	2028	2029	2030
Virgin viscose production costs	14.649 €	14.463 €	13.183 €	11.633 €	9.821 €	7.776 €
Recycled viscose production costs	222 €	2.972 €	5.591 €	7.989 €	10.053 €	11.664 €
Personnel Costs	€ 6.726	€ 8.088	€ 8.926	€ 9.554	€ 9.904	€ 9.908
Other Operating expenses	€ 3.633	€ 4.207	€ 4.477	€ 4.626	€ 4.636	€ 4.488
Blockchain OPEX	98 €	98 €	98 €	98 €	98 €	98 €

Table. 37 - CS2 Operating Costs: Fibre Producer

Accordingly, the resulting trend in operating margin provide encouraging positive outcomes shown in Figure 46.

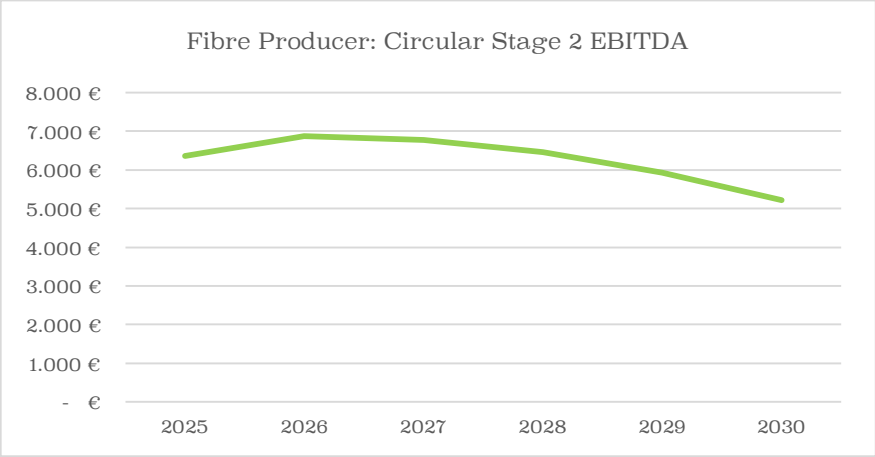

Figure. 46 - Fibre Producer: Circular Stage 2 EBITDA

Moreover, for what regards blockchain CAPEX, the total accounting for development costs and additional consulting, visual and technical design stays at € 551. On the other side, as anticipated, also the product stewardship fees' burden is reduced as shown in table 38.

	2025	**2026**	**2027**	**2028**	**2029**	**2030**
CS2 PS Fees: Fibre Producer	€ 122	€ 96	€ 90	€ 82	€ 74	€ 65
CS2 Discounts (vs CS1)	43 €	73 €	103 €	138 €	179 €	226 €

Table. 38 - CS2 PS Fees & Discounts: Fibre Producer

CIRCULAR STAGE 3 SCENARIO

In conclusion, the last scenario to analyse entails the whole comprehensive application of all postulated features of the framework. The difference in respect to Circular Stage 2, lies in the adoption of eco-design principles and consumer awareness raising actions, thus generally facilitating and pushing an overall reduction of physical products and wastes flows. The legitimate consequence will thus be an empowerment of servitisation business models, driving the transition from an economy based on the sale of goods to one based on the sale of performance.

CS3 Collector & Sorter

The full implementation of the proposed framework may represent a key game changer for the end-of-life infrastructure. Overall waste volumes will be reduced but the incentives towards greater performances in durability, reusability and recyclability combined with an improved care during the use phase will widely support the economic persistence of collectors and sorters.

In these regards volumes recovered follow the formula unfolded in Circular Stage 2, only basing on lower production and sale quantities at retails stage.

Similarly, revenue streams and cost typologies adhere to the assumptions made above, as shown in tables 39 and 40.

CS3 Revenues: Collector & Sorter	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Second-hand clothing resale	33.625 €	42.543 €	50.699 €	60.144 €	71.056 €	83.633 €
"Original" resale	14.307 €	14.704 €	14.246 €	13.743 €	13.204 €	12.640 €
Resale for Open-Loop recycling	99 €	89 €	72 €	53 €	33 €	10 €
Resale for Closed-Loop recycling	111 €	2.409 €	4.884 €	7.540 €	10.374 €	13.383 €

Table. 39 - CS3 Revenues: Collector & Sorter

CS3 Operating Costs: Collector & Sorter	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Differentiated Collection costs	21.067 €	24.411 €	26.752 €	29.292 €	32.045 €	35.029 €
Maximum bid	3.117 €	3.505 €	3.731 €	3.971 €	4.227 €	4.498 €
Sorting	1.013 €	1.185 €	1.310 €	1.446 €	1.593 €	1.754 €
Disposal costs	315 €	288 €	234 €	169 €	95 €	10 €
Personnel costs	9.802 €	11.430 €	12.601 €	13.874 €	15.259 €	16.763 €
Leasing costs	1.950 €	2.263 €	2.484 €	2.724 €	2.985 €	3.267 €
Other operating costs	2.976 €	3.694 €	4.321 €	5.037 €	5.852 €	6.780 €
Services	16.546 €	20.942 €	24.977 €	29.669 €	35.115 €	41.426 €
Blockchain OPEX	194 €	194 €	194 €	194 €	194 €	194 €

Table. 40 - CS3 Operating Costs: Collector & Sorter

Accordingly, the resulting curve of operating margin is characterised by a positive change of trend shown in Figure 47.

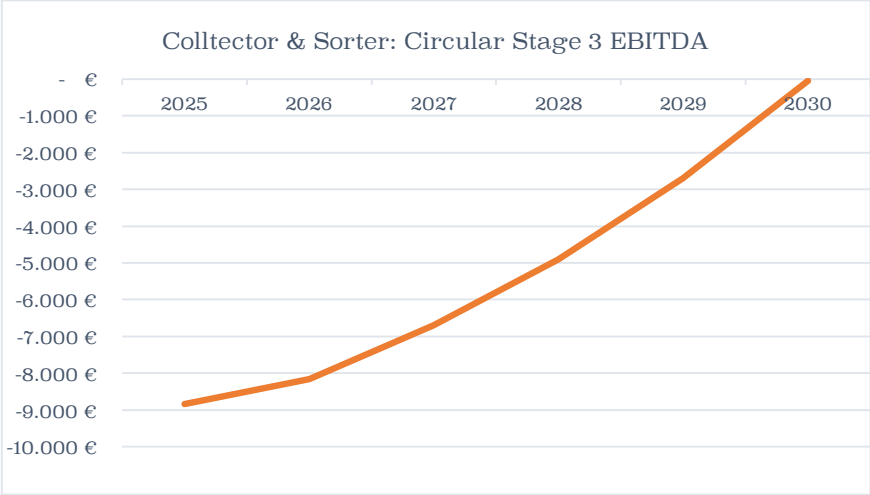

Figure. 47 - Colltector & Sorter: Circular Stage 3 EBITDA

In respect to investments, the usual assumption for the Fibersort and blockchain technology CAPEX result in a total of € 30.551. Furthermore, consistently to the trend in operational net costs, subsidies required will be characterised by a lower magnitude and a decreasing trend, as shown in table 41.

	2025	**2026**	**2027**	**2028**	**2029**	**2030**
CS3 Subsidies to Collector & Sorter	€ 10.383	€ 8.165	€ 6.703	€ 4.897	€ 2.698	€ 55

Table. 41 - CS3 Subsidies to Collector & Sorter

CS3 Retail Brand: MUD Jeans

In accordance with the features of this scenario, the retail stage is expected to reduce volumes produced but still maintain or enhance profitability through adapting the business models and communication strategies.

In respect to the limited availability of data, revenues and costs patterns will be modified only basing on the change of quantities in flows. The resulting income and expenses streams will thus adhere to the assumption made in the previous scenario, as shown in tables 42 and 43.

CS2 Revenues: Retail Brand	2025	2026	2027	2028	2029	2030
Traditional sales	€ 3.473.881	€ 3.831.032	€ 3.975.629	€ 4.096.293	€ 4.184.257	€ 4.228.937
Recondition BM sales	63.038 €	76.385 €	87.108 €	98.645 €	110.766 €	123.085 €
Rental sales	1.269.230 €	1.610.271 €	1.933.386 €	2.320.631 €	2.784.585 €	3.340.362 €
Discounted sales	1.155.443 €	1.276.032 €	1.326.247 €	1.368.829 €	1.400.842 €	1.418.717 €
Closed-loop sales	705 €	1.449 €	2.262 €	3.196 €	4.267 €	5.490 €
Open-loop sales	521 €	538 €	519 €	493 €	459 €	415 €

Table. 42 - CS2 Revenues: Retail Brand

CS2 Operating Costs: Retail Brand	2025	2026	2027	2028	2029	2030
Textile input costs	654.922 €	723.274 €	751.737 €	775.873 €	794.018 €	804.150 €
Total Production costs	1.091.537 €	1.205.457 €	1.252.895 €	1.293.121 €	1.323.364 €	1.340.250 €
Disposal costs	547 €	529 €	460 €	367 €	248 €	98 €
Selling, general and administrative costs	2.810.652 €	3.303.589 €	3.671.539 €	4.076.746 €	4.524.158 €	5.020.434 €
Discounting (rewards)	179.487 €	201.922 €	215.047 €	229.026 €	243.912 €	259.767 €
Reverse logistic costs	15.129 €	17.362 €	18.855 €	20.469 €	22.212 €	24.096 €
Blockchain OPEX	27.540 €	27.540 €	27.540 €	27.540 €	27.540 €	27.540 €

Table. 43 - CS2 Operating Costs: Retail Brand

Accordingly, it is noticeable how the trend in operating margin remaining promisingly positive resembling the curve displayed for Circular Stage 2, as shown in chart 48.

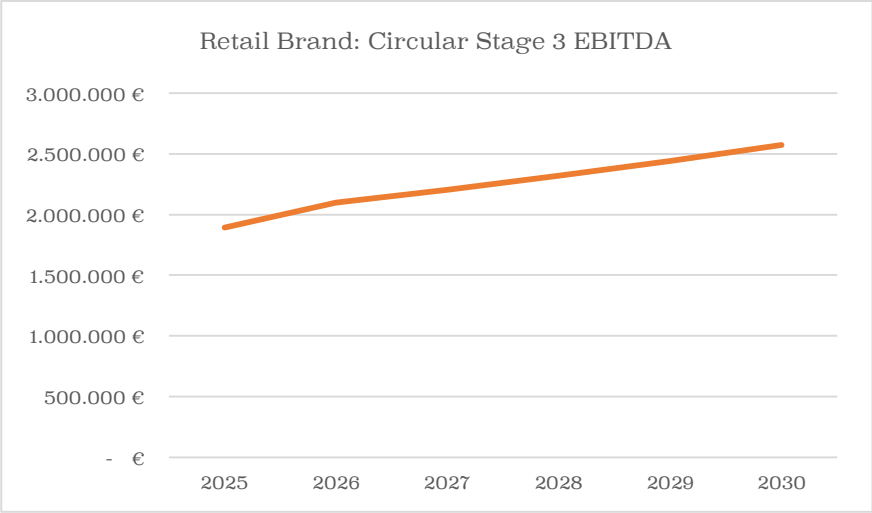

Figure. 48 - Retail Brand: Circular Stage 3 EBITDA

Beyond this, blockchain expenses are again beard for their totality in the case of the retail brand. CAPEX thus amount for € 118.728.

Finally, given the support for the circular management of flows and the increase in quality, durability, reusability and recyclability, the burden of fees will be weaker, i.e. characterised by a small magnitude and by a decreasing trend, as shown in table 44.

	2025	**2026**	**2027**	**2028**	**2029**	**2030**
CS3 PS Fees: Retail Brand	€ 9.733	€ 7.657	€ 6.289	€ 4.597	€ 2.535	€ 51
CS3 Discounts (vs CS1)	7.926 €	10.467 €	14.316 €	18.997 €	24.629 €	31.153 €

Table. 44 - CS3 PS Fees and discounts: Retail Brand

CS3 Fabric Producer

Since the changes of this scenario impact mostly the stages downstream in the value chain, patterns of the fabric producer will widely resemble the ones deployed in Circular Scenario 2, as shown in tables 45 and 46. The major difference lies in the implementation of eco-design principles which shall induce an improvement in efficiency of processes also upstream. Therefore, overproduction is estimated at 1%, similarly to performance of the fibre producer already in the present, instead of current state level of 12% (Foundation, 2017).

CS3 Revenues: Fabric Producer	2025	2026	2027	2028	2029	2030
Total revenues	654.922 €	723.274 €	751.737 €	775.873 €	794.018 €	804.150 €

Table. 45 - CS3 Revenues: Fabric Producer

CS3 Operating Costs: Fabric Producer	2025	2026	2027	2028	2029	2030
Textile input costs	133.704 €	152.520 €	162.271 €	170.066 €	175.434 €	177.867 €
Price of virgin material	132.148 €	118.964 €	95.228 €	68.583 €	39.429 €	8.434 €
Price of recycled material	1.557 €	33.557 €	67.043 €	101.482 €	136.005 €	169.433 €
Total production costs	194.085 €	221.398 €	235.552 €	246.867 €	254.660 €	258.192 €
Disposal costs	- €	- €	- €	- €	- €	- €
Leasing costs	82.236 €	90.819 €	94.393 €	97.423 €	99.702 €	100.974 €
Personnel costs	225.410 €	258.155 €	277.896 €	296.709 €	313.770 €	328.024 €
Blockchain OPEX	242 €	242 €	242 €	242 €	242 €	242 €

Table. 46 - CS3 Operating Costs: Fabric Producer

Accordingly, it is noticeable how the trend in operating margin resembles the curve displayed for Circular Stage 2, as shown in Figure 49.

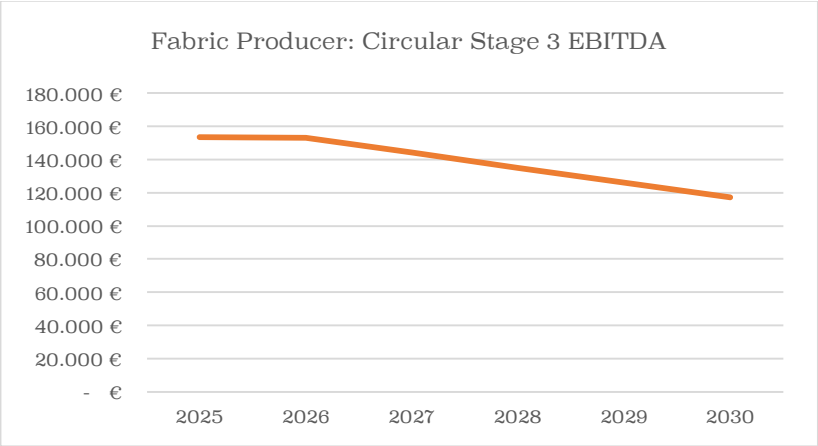

Figure. 49 - Fabric Producer: Circular Stage 3 EBITDA

For what regards blockchain first year investment, a total of € 1.043 referring to this specific stream of goods analysed, covers development costs as well as additional consulting, visual and technical design.

According to the ultimate and complete application of the proposed model, product stewardship fees will reduce their weight also in this stage, as shown in table 47.

	2025	2026	2027	2028	2029	2030
CS3 PS Fees: Fabric Producer	251 €	208 €	180 €	146 €	107 €	63 €
CS3 Discounts (vs CS1)	2.382 €	2.501 €	2.900 €	3.379 €	3.951 €	4.597 €

Table. 47 - CS3 PS Fees and Discounts: Fabric Producer

CS3 Fibre Producer

As abovementioned also the economic situation of this stage of fibre production and recycling won't change a lot in respect to Circular Stage 2. The resulting revenues and operational costs structures will be shown in table 48 and 49. In particular, the sales price for recycled viscose is assumed in this case to stay constantly at a 50% higher costliness in respect to virgin viscose production. The reasons for this estimation lie in the growth of currently almost inexistent markets in the reverse supply chain, enabling higher profitability potentials and business interest. Furthermore, once eco-design principles will be in place, qualitative closed-loop raw materials shall be valued more.

CS3 Revenues: Fibre Producer	2025	2026	2027	2028	2029	2030
Virgin viscose sales	21.658 €	19.423 €	15.491 €	11.117 €	6.370 €	1.358 €
Recycled viscose sales	328 €	7.193 €	14.608 €	22.470 €	30.592 €	38.707 €

Table. 48 - CS3 Revenues: Fibre Producer

CS3 Operating Costs: Fibre Producer	2025	2026	2027	2028	2029	2030
Virgin viscose production costs	10.161 €	9.227 €	7.447 €	5.405 €	3.130 €	674 €

Recycled viscose production costs	154 €	3.189 €	6.086 €	8.739 €	11.024 €	12.810 €
Personnel Costs	4.666 €	5.866 €	6.879 €	7.951 €	9.051 €	10.138 €
Other Operating expenses	2.520 €	3.051 €	3.450 €	3.850 €	4.237 €	4.593 €
Blockchain OPEX	82 €	82 €	82 €	82 €	82 €	82 €

Table. 49 - CS3 Operating Costs: Fibre Producer

These negligible amounts of expenses for blockchain implementation in the case of the fibre producer are determined by the tremendously greater size of the overall business in respect to the flow of materials analysed here.

Anyhow, the resulting trend in operating income will be the following, shown in Figure 50.

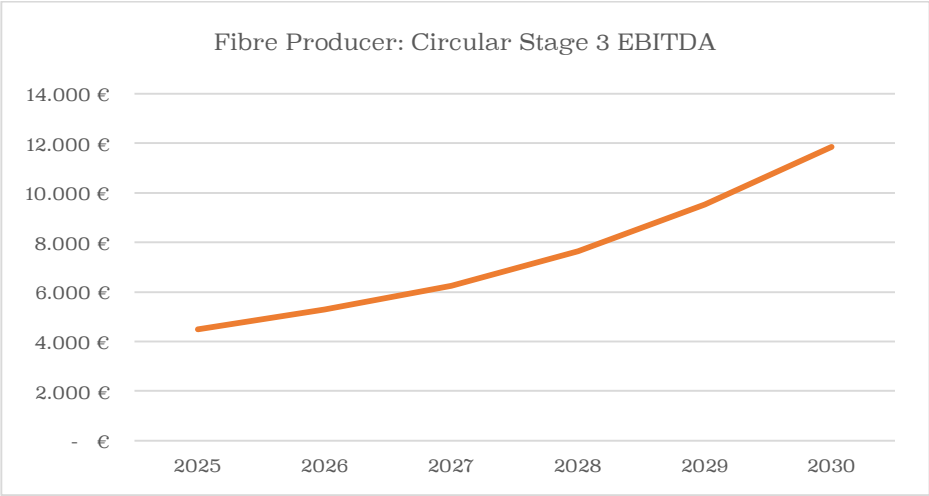

Figure. 50 - Fibre Producer: Circular Stage 3 EBITDA

Furthermore, in accordance with the reasoning over operational blockchain costs also the related CAPEX will result in a modest € 351.

Similarly, in relation to the achievement in flows reduction and improvement of this scenario, also product stewardship fees will be sharply diminished, as shown in table 50.

	2025	2026	2027	2028	2029	2030
CS3 PS Fees: Fibre Producer	€ 90	€ 70	€ 57	€ 41	€ 23	€ 0
CS3 Discounts (vs CS1)	75 €	99 €	135 €	179 €	231 €	291 €

Table. 50 - CS3 PS Fees and Discounts: Fibre Producer

4.3.2. Economic viability test - Discussion

Once the economic analysis findings of the experimental implementation of the model are displayed, the study shall debate the structural effects that such an incentive system causes throughout the whole value chain investigated and in particular for each actor separately. The discussion will thus cover the economic short and long term sustainability levels in each supply chain stage, by comparing the outcomes and interlinks present in each scenario.

Still, the unavailability of data poses in this case a significant limitation, since it is possible to analyse only operational performances of each company. The target is to evaluate the viability of investments but, due to missing data regarding depreciation and amortisation, interest, taxes and working capital requirements, it is not possible to carry out an accurate analysis of free cash flows. In these regards, the study will cover the diversification in trends of EBITDA curves for each actor and EBITDA values will be then used to provide an approximate measure of Net Present Value. The NPV evaluation further considers the required technological investments and an estimate of cost of capital for the apparel sector of 6,04%[xiv], assumed as discount rate, for the computation of future economic flows. The approximate formula will thus be the following:

$$NPV_{(t)} = I_0 + \sum_{t=0}^{5} \frac{EBITDA_t}{(1+d)^t}$$

Accordingly, the objective of the discussion is not to provide absolute numbers but to confront the different scenarios with a qualitative approach, i.e. rather examining the delta of performances and the estimated optimal or preferable strategies for each player. Consistently, the analysis will now focus on a value chain actor at a time, moving from downstream to upstream, in order to gather considerations both on single stages as well as on comprehensive supply chain effects.

The differentiation in building blocks, reflected in the scenarios of investigation, enables a more detailed evaluation of each comprised feature. The graduation helps indeed to outline the relevance of the actions and business models incentivising companies, particularly brands, to produce less and with a better quality.

Collector & Sorter

As marked along the development of the analysis, recollection and sorting processes represent the focus of subsidisation, facilitation and optimisation in a top-down approach in this implementation case and in general within the proposed framework. This actor received indeed financing from the various supply chain collaborators in order to reach the breakeven point and propel the whole reverse value chain functioning.

The benefit of application of product stewardship schemes is evident, as the negative value of the approximated NPV is neutralised already in Circular Stage 1, by reaching parity of revenues and operational expenses, thanks to the subsidies applied, as shown in table 51. The discussion shall thus focus on the contributions deriving from the application of the specific Blockchain-enhanced Product Stewardship Framework proposed.

NPV	***BAS***	***CS1***	***CS2***	***CS3***
Collector & Sorter	-51.624 €	-	-	-

Table. 51 - NPV Collector & Sorter

As shown in Figure 51, the negative effect of Circular Stage 1 is given in this case of implementation by the fact that the subsidisation of the end-of-life infrastructure permits a more efficient collection of much greater volumes of used clothing, but still does not act enough on the unbalance between rising costs and shrinking reusable fractions, which squeezes collectors and sorters.

The multiplied volumes thus translate into higher management costs with constantly declining revenue streams, i.e. driving down EBITDA performances.

On the other hand, Circular Stage 2 provides a large improvement, since the downward sloping trend is reversed and the new curve offers hope also for higher future long term economic persistence. As a matter of fact, the implementation of firm-level reverse logistic systems and rental or resale business models puts more responsibilities in the hands of brands and incentivised them to research more favourable quality and reusability performances, accordingly spurring the improvement also upstream and downstream along the value chain.

Beyond this, Circular Stage 3 represents one more step forwards in the sense that consumer awareness campaign and eco-design for longevity, reusability or recyclability become guiding principles among supply chain actors. As a result, used clothing volumes reaching collectors and sorters will be less and characterised by better conditions, thus lowering sorting costs and enhancing a lot the yield from the 'Reusable' revenue stream.

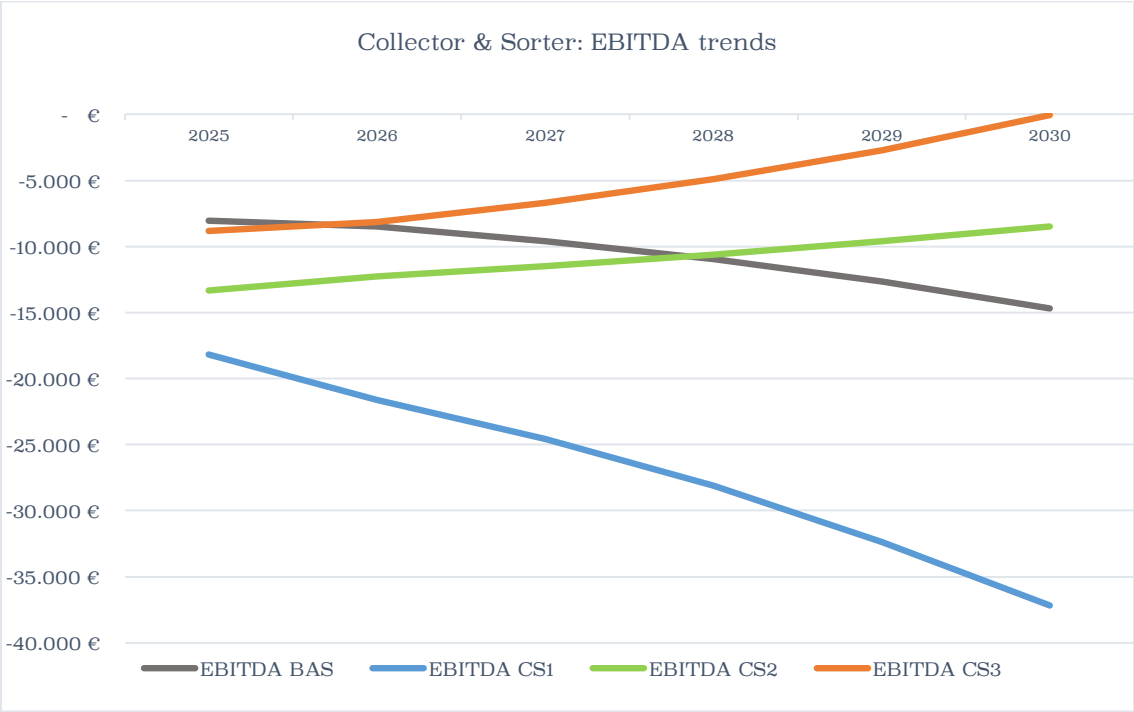

Figure. 51 - Collector & Sorter: EBITDA trends

Retail Brand

As anticipated, the role of brands becomes fundamental when inducing the full adoption of valuable circular patterns of production, consumption and waste creation.

In this case, it has to be noticed that the lack of cost data regarding repair services, consumers' awareness campaigns and other additional circular investments, widely affect the results found. Still the magnitude of difference in NPV computations provides a constructive indication of preferable scenarios.

In particular, as observable both in table 52 and figure 52the establishment of the first building block, i.e. the application of basic product stewardship schemes, do not offer great incentives for brands. The resulting economic outcome is even slightly lower than Business-As-Usual, given the fact that the organisation will have to bear higher regulative costs without receiving great improvements on the income side.

Conversely, the circumstances are revolutionised with the implementation of Circular Scenario 2, since the diversification in business models supports an expansion of the customer base and a generally wide uplift in profitability, obtaining soaring revenues recovering and reutilising the same resources. Consistently, Circular Stage 3 pushes for even higher productiveness, reducing overproduction and increasing product quality, durability, reusability and recyclability, thus prolonging the lifespan and income potential of each item. In accordance, the latter two EBITDA trends are both characterised by a positive slope, with one curve slightly higher than the other.

NPV	***BAS***	***CS1***	***CS2***	***CS3***
Retail Brand	2.976.156 €	2.816.091 €	9.244.057 €	10.813.915 €

Table. 52 – NPV Retail Brand

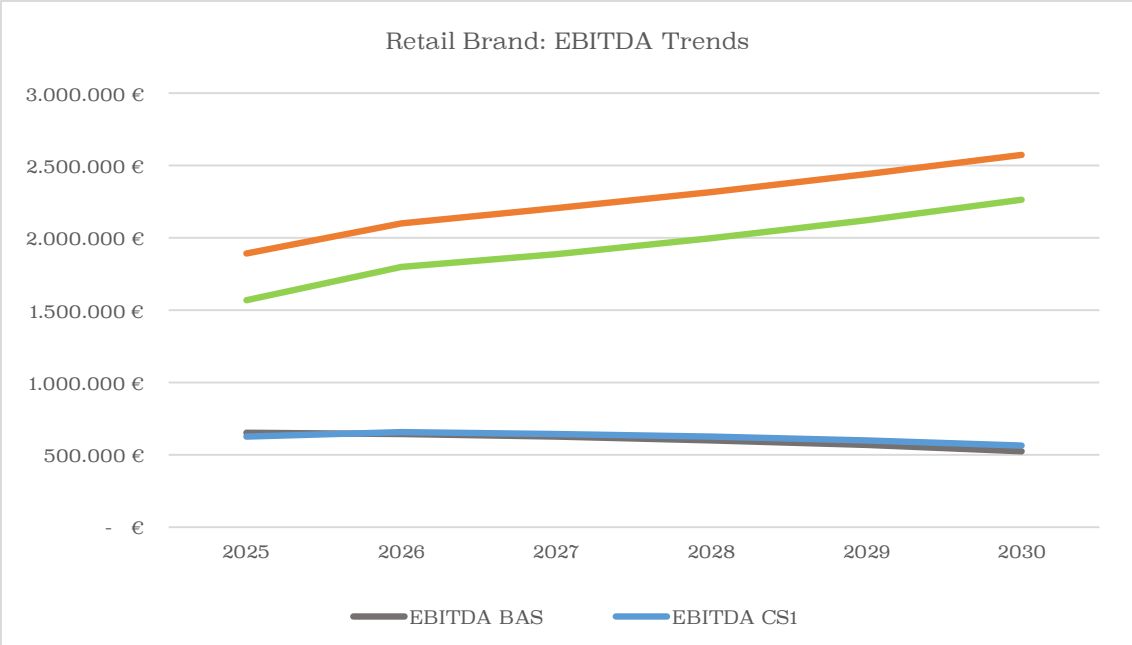

Figure. 52 - Retail Brand: EBITDA Trends

Fabric Producer

For what regards the so-called "Sandwich spectator" (Franco, 2017), structural outcomes from the implementation of the BC-PS framework proposed are positive but uncertain.

As shown in table 53 and figure 53, the gradual addition of the modelled building blocks favours a measured but continuous improvement in economic operational performances. Still, the reduction of quantities to be produced weighs more in the upstream stages and causes the permanence of a downward sloping trend in EBITDA. Operating margin values will thus be higher in magnitude but still decline along the years.

Actors in this supply stage shall find alternative ways for raising processes efficiency and better proposing its products, gaining higher price premiums for the efforts in direction of sustainability and circularity. In these regards, blockchain technology may represent a key game changer in the sense that it allows both to reduce inefficient operations, support decision making for further processes improvement and provide advanced traceability for a better commercialisation of products and obtainment of valuable certifications.

NPV	BAS	CS1	CS2	CS3
Fabric Producer	536.447 €	552.910 €	669.442 €	683.510 €

Table. 53 - NPV Fabric Producer

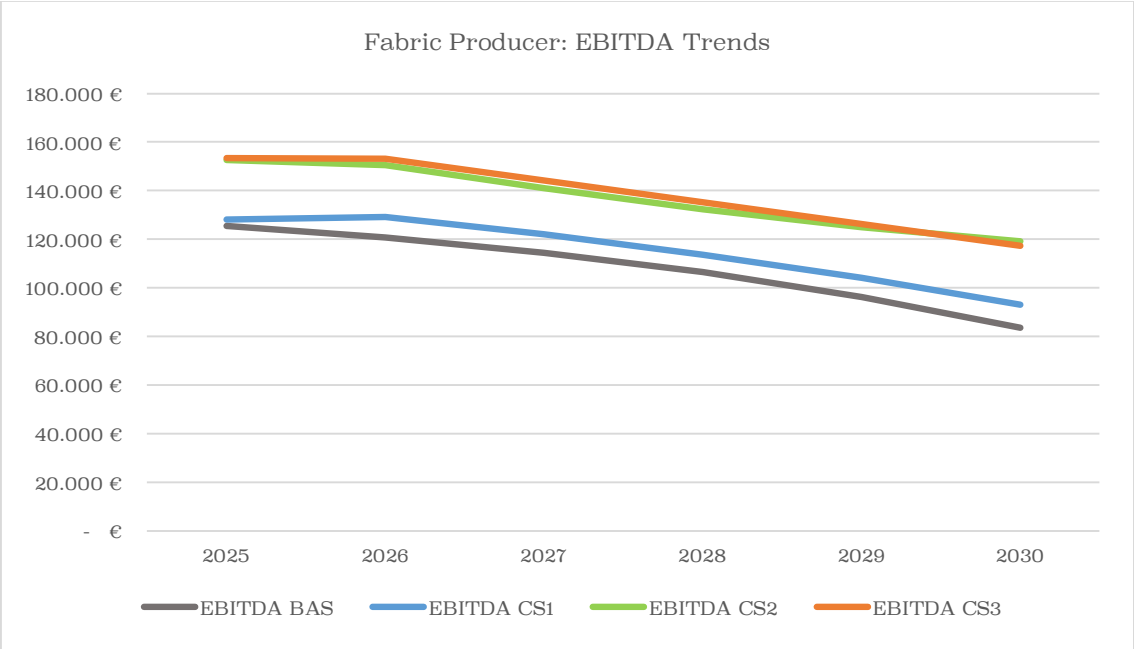

Figure. 53 - Fabric Producer: EBITDA Trends

Fibre Producer

The rebound effect of the circular economy paradigm entails the major impact relevance for the raw material production stage, which may be potentially squeezed between reduced production levels and innovative business models in the downstream stages of the value chain.

As shown in table 54 and figure 54, the outcomes of the framework application are not linear. Circular Stage 1 represents a positive improvement in respect to Business-As-Usual, given the incentives and quantitative enhancement of closed-loop flows, thus favouring recycled inputs. Within Circular Stage 2, on the other hand, the burden of lower production volumes outweighs any improvement in quality and sustainability of the material mix. Finally, Circular Stage 3 EBITDA curve starts at lower levels than the previous one, given the even lower quantities demanded, but then outpaces all others and reaches

much higher levels of profitability, constantly following a positive slope. This result correlates with the widely grown percentage of closed-loop flows and with the assumption that in the case in which brands comply with eco-design principles for longevity, reusability and recyclability, then qualitative and circular yarns shall be valued more, i.e. enabling the maintenance of high price premiums along all the years of analysis.

Accordingly, the business case thus holds consistence only if fibre producers will adapt to the modified materials requirements and be able to become also recyclers, thus perfectly entering the value loop.

NPV	***BAS***	***CS1***	***CS2***	***CS3***
Fibre Producer	41.536 €	45.794 €	30.143 €	35.039 €

Table. 54 - Fibre Producer

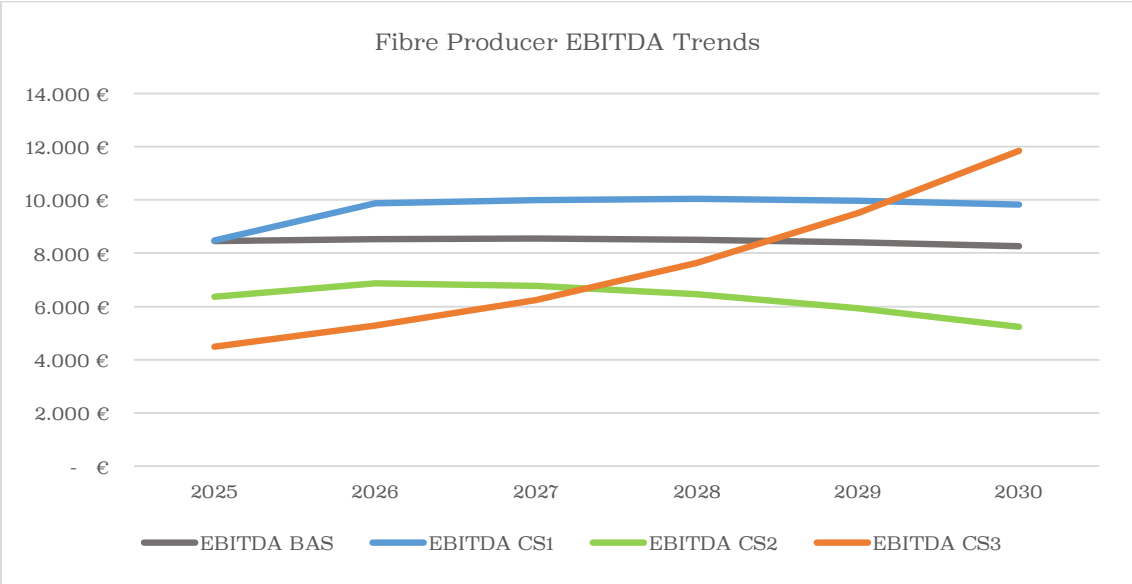

Figure. 54 - Fibre Producer EBITDA Trends

In conclusion, supply chain effects produced by the implementation of the framework appear to be more favourable in downstream stages, but still offer profitability benefits also upstream. Considering both EBITDA trends and approximate NPV values, it is possible to estimate preferable strategies for each player, as shown in table 55.

NPV	BAS	CS1	CS2	CS3
Fibre Producer	41.536 €	45.794 €	30.143 €	35.039 €
Fabric Producer	536.447 €	552.910 €	669.442 €	683.510 €
Retail Brand	2.976.156 €	2.816.091 €	9.244.057 €	10.813.915 €
Collector & Sorter	-51.624 €	-	-	-

Table. 55 - Approximation of NPV values for each supply chain actor in each scenario

It is important to remark, that given the presence of various assumptions and lacks of data, the results shall be analysed through a differential approach, i.e. not focusing on absolute values but rather on the deltas present among different alternative options for each player.

The general outlook of value chain actors' conditions enlightens a preferability for the full application of the model (CS3), through the integration of all building blocks. The integration of product stewardship principles with individual firm advancements shall thus provide the required synergy to propel the closed-loop functioning of the supply chain and further reduce waste expansion thanks to the reduction in volumes produced.

Still, only the fibre producer may strategically choose to settle in Circular Stage 1 where overall volumes remain high and the percentage of recycled materials rises gradually. The problem remains clear, since the main rebound effect of circular economy systems remains the disadvantaging of raw materials suppliers in relation to the higher circulation of existing resources. In relation to this and in general, players may still position in a multifarious way among the possible alternatives. Computed discount values shall thus be applied in a customised matter, adapting to the specific performances strategy decided and deployed by each actor. Consistently, the ability to directly link a specific set of actions to a specific fee and discounts level, players shall be incentivised to improve further towards higher sustainability and circularity levels.

Furthermore, referring to less favoured upstream stages, the model shall still also drive higher collaboration along the value chain, reducing the pressure on middle stage players and raising the significance of upstream performance improvements. As a matter of fact, the collaboration entails also the potential to enhance innovativeness, particularly given the weight of material impacts on the overall environmental impact balance of a garment. In relation to the reduction of volumes in Circular Stage 3, the model pushes also for innovations in the value proposition of the company, expanding the product offer in the

direction of servitisation thus improving service levels and performances for each supply chain actor.

Beyond all this, the validation process demonstrates the value of differentiated incentive approach, in which to facilitate both end-of-life managements infrastructures and single firms in the direct supply chain. Accordingly, the test deployed provides proof for the robustness and significance of the novel framework proposed, from an economic point of view.

The testing process shall thus now consider the impacts on the ecosystem of the constructed value chain, differentiating among the 4 scenarios of application of the model, again enabling a gradual evaluation of each set of features entailed.

4.4. ENVIRONMENTAL SUSTAINABILITY TEST

As exposed in the methodology section, a Life Cycle Assessment procedure is carried out in order to consider an end-to-end perspective of the product under analysis and in order to draw conclusions on a wide spectrum of computed impact categories.

The inherent mechanism to test is thus the effectiveness and the width of effects of a modification in the diverse possible product and waste flows percentages impacting on the increase in environmental performances, once a certain value redistribution scheme is put in place.

In these regards, the first and main challenge for an LCA practitioner will be to develop the LCA model in such a way that the simplifications and distortions do not influence the results too much ('Introduction to LCA with SimaPro Colophon', 2013). Technical parameters used will base on the 'General assumptions' chapter (**See Section 4.2.**), thus exploiting standard processes present in the 'Ecoinvent 3 – consequential – unit' database of Simapro and mirroring the MUD Jeans value chain structure displayed also for the economic analysis by adjusting the distribution of percentages of waste and value flows. Consequently, for the sake of systematising the procedure used, it is relevant to fix the goal and scope of this LCA analysis, which follow the guidelines of the Product Category Rules of the International EPD® System specifically for trousers.

GOAL & SCOPE

The general objective is to test the indirect relation present between top-down incentives-driven economic sustainability and higher environmental sustainability, under specific conditions of value redistribution and scaling up of favourable processes and business. Hence, the related reasons for the study entail the evaluation of the magnitude of changes in impact categories performances in relation to changes in flows structure, aiming to support meso- and macro-decision making. The intended audience would comprise EPR regulators and all stakeholders of the European fashion industry.

In particular, in order to achieve the abovementioned objective, the design of comparison case is fundamental. The scenarios investigated will thus be the same four used in the economic analysis, but the LCA will study the impacts of the value chain as a whole, so not considering single actors, since the target is a widespread improvement for the whole ecosystem and not for isolated sustainability champions, as it is already occurring without great results in the current state.

In summary the comparison will entail:

- ***Business-As-Usual - Value chain scenario***: Characterised by high production and waste levels, low recycling levels, as well as wrong care and disposal habits, causing detrimental environmental effects

- ***Circular Stage 1 - Value chain scenario***: Characterised by an increase in waste management and resource recovery systems, enhancing textile-to-textile recycling levels

- ***Circular Stage 2 - Value chain scenario***: Characterised by an increase in usage longevity of clothes exchanged among diverse consumers, thus shrinking the production demand and the creation of waste

- ***Circular Stage 3 - Value chain scenario***: Characterised by a further increase in durability, reusability and recyclability as well as in consumer consciousness and improved use phase care

Accordingly, material requirements will widely vary among the analysed scenarios and it is thus crucial to establish a solid and unique functional unit.

It is assumed that clothing performs a number of functions for the wearer, which can generally be categorised into two broad aspects. There are the technical functions of meeting the fundamental needs of the wearer; warmth and the protection of modesty. There are also emotional needs or desires, where clothing acts as a set of symbols that reflect our personality and identify us with certain groups; clothing is a communication device about the individual to society (WRAP, 2015b).

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The functional unit considered is thus the <u>average use of jeans over 5 years of analysis, worn every day.</u>

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The length of the period is designed to align to the features of the economic analysis and to use a timeline long enough to assess the concrete effect of reuse and durability performances enhancement.

The approach followed is *Cradle-To-Cradle*.

Consistently, the system boundaries entail the supply, production, use and recovery of jeans, as shown in figure 55. Specifically, production and disposal of capital goods is excluded from the analysis; while, boundaries to nature are assumed till the growing of cotton and trees for viscose production.

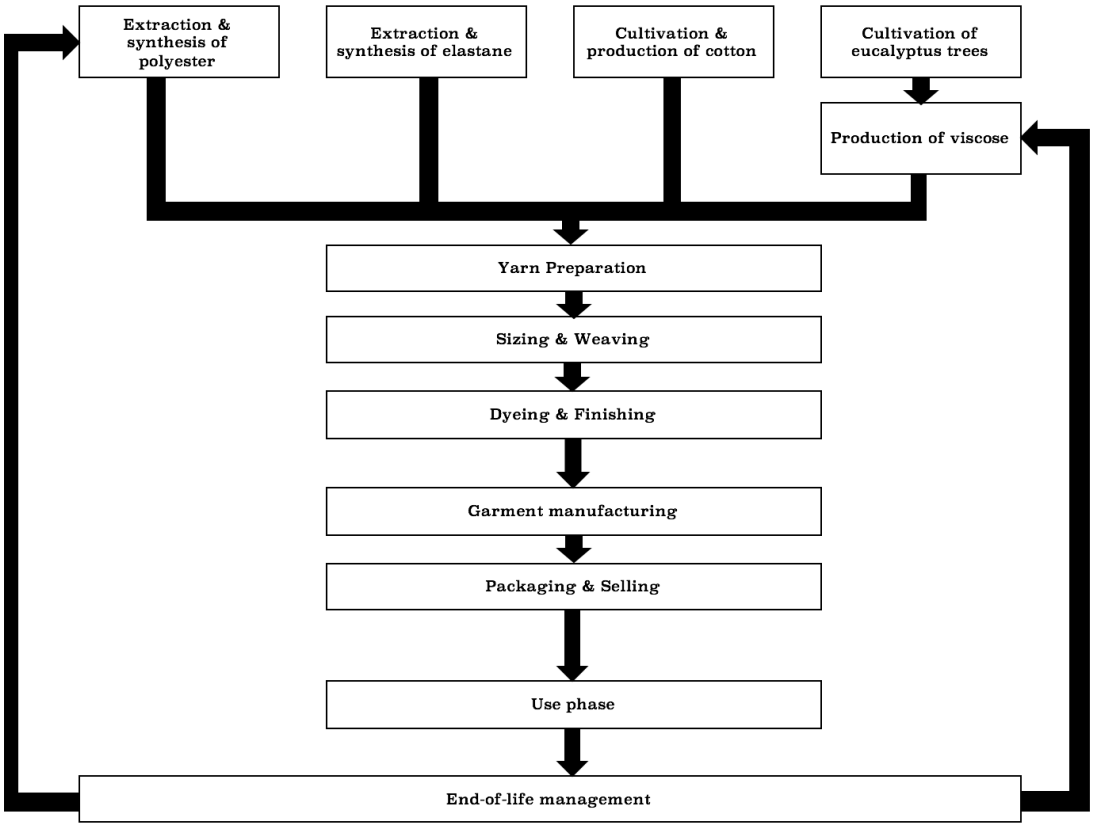


Figure. 55 - LCA System Boundaries

The geographical outlook of this value chain positions the cotton producer in India, the polyester and elastane producer in China, whereas the viscose producer and recycler in Austria. Yarn preparation, sizing & weaving, dyeing and finishing are performed in Italy. Garment manufacturing, quality checks, packaging and sale are performed in the Netherlands. The use phase and end-of-life management on the other hand take place again in Italy. Consistently, this network partly reflects the complexity of flows characterising the fashion industry.

4.4.1. Life Cycle Assessment - Findings

Aligning to the order followed for the economic assessment above, the analysis will now go through each designed scenario, from the Business-As-Usual to the full implementation of the framework proposed. In particular, a detailed outlook of the main steps of the procedure followed for the creation of a coherent model within the software will be displayed Annex III.

BUSINESS-AS-USUAL SCENARIO

This scenario mirrors the current state situation, i.e. it embodies over-production and over-consumption patterns of goods which then get degraded more than necessary and are disposed in the wrong way. Indeed, it is assumed that, on average, consumers own 6 pairs of jeans, globally (Chapagain *et al.*, 2006). Their production comes with both positive effects, such as economic development, and also burdensome negative effects on society (Impact Institute, 2019). Under these conditions, the durability of a pair of jeans is estimated of 40 washes (*Int. 5*), corresponding in this case to 10 months, since it is also assumed that the average consumer will wash the jeans once per week (Levi Strauss & Co, 2015).

The technical features constituting the Business-As-Usual scenario are thus the use of 6 pairs of jeans over the 5 years analysed, produced with mainly virgin raw materials and adhering to the following sourcing, disposal and recovery percentages, according to some additional assumptions to adapt flows to the availability of processes in Simapro and to the current state of the overall industry ecosystem:

- *Landfill/Incineration: 85%* - This result is given by impossibility to take care with specific Simapro processes of the flows accounting for the losses in production and losses in recollection and processing, that were thus added to the 73% of flows being finally disposed of (Foundation, 2017)

- *Cascaded Recycling: 12%* - Consistent estimate with the related flow (Foundation, 2017)

- *Closed loop: 3%* - This result is given by the 1% of closed-loop recycling estimated in the report of 'A new textiles economy", added to the 2% open-loop recycling estimated which could not be transferred in the software according to the chosen system boundaries (Foundation, 2017)

These percentages where then applied to the specific quantity of jeans. The related weight of the single pair was computed basing on the estimates used in the general parameters (**See Section 4.2.**), reflecting 1,5 yards[xv] of a 60" wide fabric[xvi] with an average weight[xvii] of 13 oz/ya^2, thus resulting in an overall weight of 0,923 kg per pair of jeans. This measure was then subdivided according to the four-fold materials flows applied within the 'Known inputs from technosphere' in the process for the definition of jeans production characteristics for each scenario, comprising: 67% cotton entered as 'Textile, woven cotton [GLO] | production | Conseq, U', 17% viscose entered as Viscose fibre [GLO] | viscose production | Conseq, U', 14% polyester entered as 'Polyethylene terephthalate, granulate, amorphous [RoW] | production | Conseq, U' and 2% elastane entered as 'Polyurethane, rigid foam [RoW] | production | Conseq, U'.

In particular, 'Closed Loop' percentages were applied to the product system designed with the 'Avoided impact of production'. 'Cascaded Recycling' percentages were included within the designed waste scenario under 'Materials and/or waste types separated from waste stream', applying the process 'PET (waste treatment) [GLO] | recycling of PET | Conseq, U'. Whilst finally 'Landfill/Incineration' percentages were included within the designed waste scenario under 'Waste streams remaining after separation', applying the process 'Waste textile, solid [RoW] | treatment of, municipal incineration | Conseq, U'.

As stated in the methodology, the resulting process was then linked to the relative 'Assembly', truly defining the final product. In turn, the 'Assembly' was then linked to the relative 'Life Cycle' in order to encompass also use processes, transportation and disposal alternatives within the relative 'Waste Scenario', as mentioned above. This procedure was deployed for each scenario assessed.

Accordingly, transport processes where included following the value chain network displayed above. On the other hand, washing and drying electricity requirements are computed exploiting the estimates of European averages for number of washes, temperature and type of drying process, selecting: weekly hot washes and tumbler drying (Levi Strauss & Co, 2015).

The overall results found are shown in figures 56 and 57, the former displays results according to the diverse single impact categories, the latter integrates results according to the evaluation of impact on 3 main categories: human health, ecosystems and resources depletion.

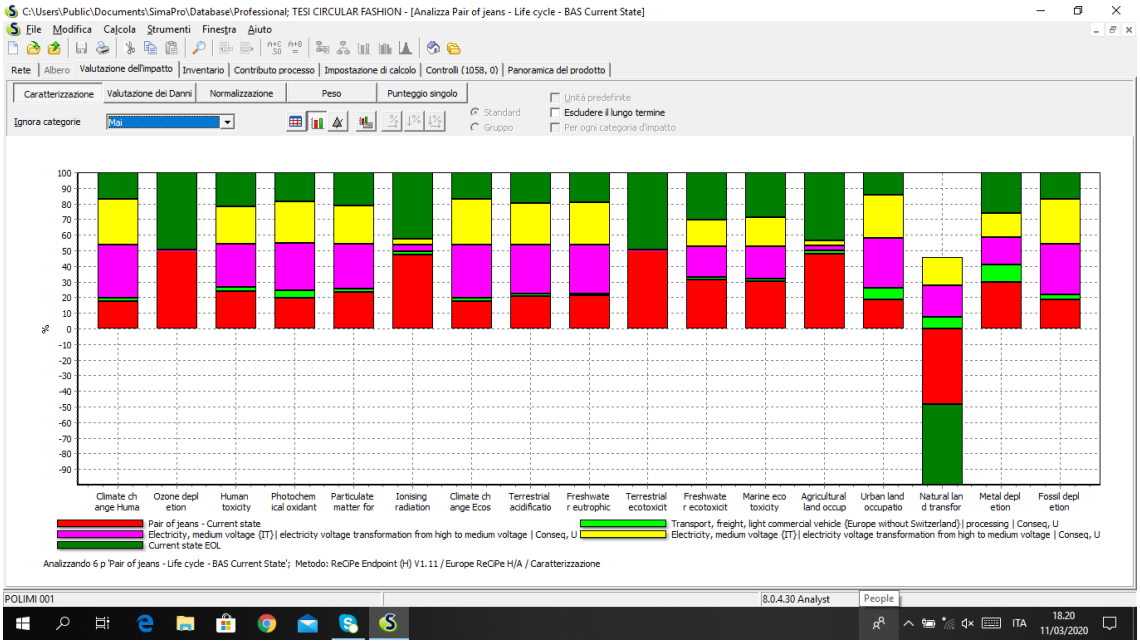


Figure. 56 - LCA Single impact categories: Business-As-Usual

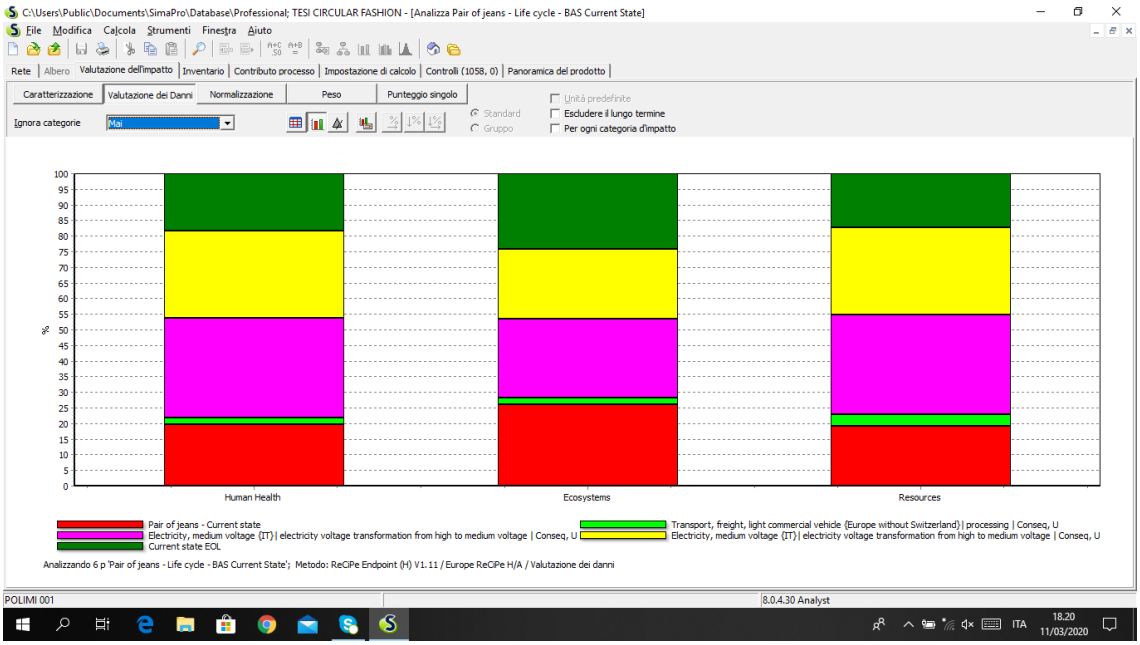


Figure. 57 - LCA Integrated impact categories: Business-As-Usual

Generally, it is possible to notice how the electricity necessary during the use phase processes of washing and drying covers the major fraction of the overall environmental impact. Beyond this, the production of jeans and thus the

manufacturing of comprised raw materials also covers a wide fraction of impacts, particularly referring to 'Ozone depletion', 'Ionising radiation', 'Terrestrial ecotoxicity', 'Agricultural land occupation' and 'Natural land transformation' (See figure x). Similarly, these categories are also the ones where the specific waste scenario has deeper effect, in relation to the high level of waste destined towards landfill or incineration. Finally, as forecastable from literature insights, transportation causes a minor fraction of pollution in relative terms against the other categories analysed.

CIRCULAR STAGE 1 SCENARIO

This scenario entails the improvement of common EOL management and reverse supply chain optimization. Under these conditions, the use of virgin resources may be minimised favouring the growth of recycled alternatives. Anyhow, since the durability and care of products is not altered by any changes at brand business models or consumer level, the longevity of the jeans will be assumed equal to the one of the Business-As-Usual scenario. The material requirements are thus again of 6 pairs of jeans for the analysed period of 5 years.

In these regards, the percentage parameters for sourcing, disposal and recovery will be the following, as displayed also for the potentials set in Circular Stage 1 in the general assumptions:

- *Landfill/Incineration: 27,84%*
- *Cascaded Recycling: 60,16%*
- *Closed loop: 12%*

As unfolded in the Business-As-Usual scenario, the procedure deployed follows similar principles in each scenario. These percentages where then thus applied to the four-fold materials flows, comprising cotton, viscose, polyester and elastane, as already unfolded.

Furthermore, transport processes where included following the value chain network displayed above, adding in this scenario 250 km for the reverse supply chain logistic management, according to the hypothesis of economic

sustainability exposed in the structuring of flows (EURATEX, 2017). On the other hand, washing and drying electricity requirements are computed exploiting the estimates of European averages for number of washes, temperature and type of drying process, selecting: weekly hot washes and tumbler drying (Levi Strauss & Co, 2015).

The overall results found are shown in figures 58 and 59.

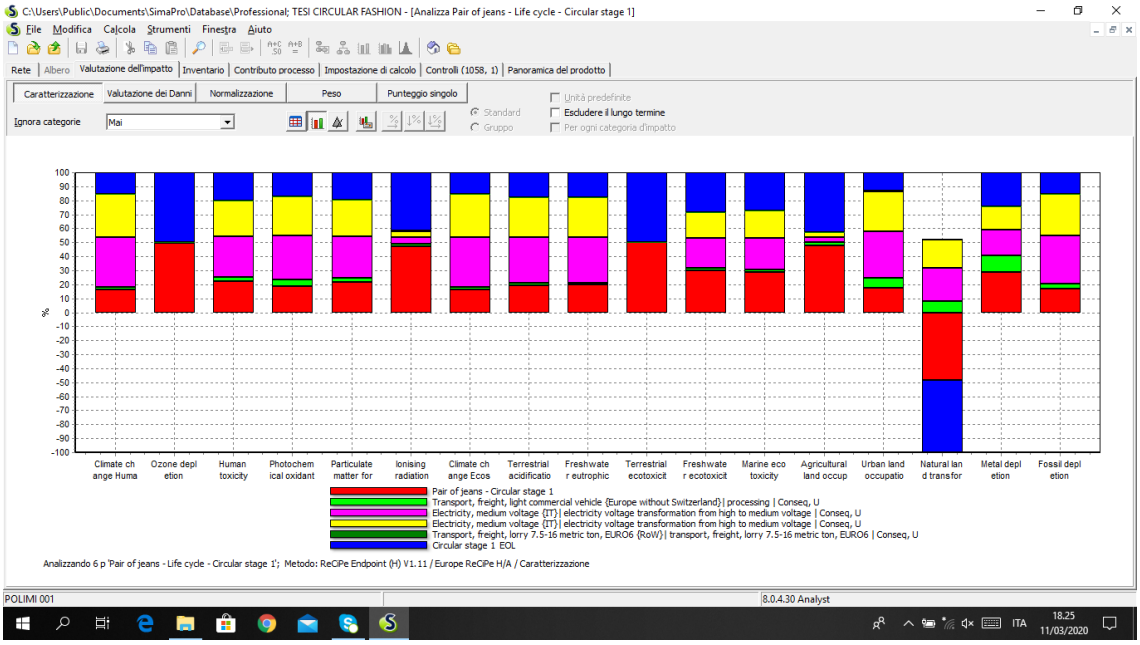


Figure. 58 - LCA Single impact categories: Circular Stage 1

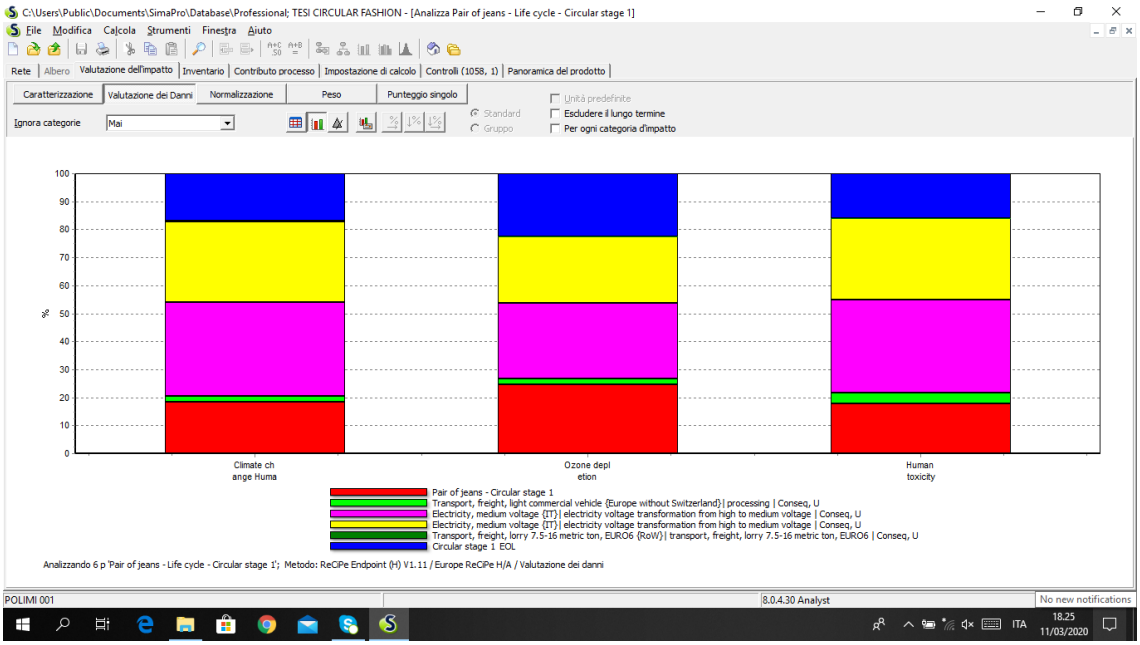


Figure. 59 - LCA integrated impact categories: Circular Stage 1

The findings of the analysis show a similar pattern in relation to the one identified in the Business-As-Usual. What emerges is a shrinkage in impacts both for what regards the production of the pair of jeans and related input fibres (in red) as well as the waste scenario (in blue). The former effect is given by the increase in percentages of recycled inputs, in the form of 'Avoided impacts'. The latter effect is given by the increase in percentage of cascaded recycling, decreasing the volumes of textile reaching landfills and incineration.

CIRCULAR STAGE 2 SCENARIO

This scenario entails the application of re-use strategies, i.e. individual reverse logistics, renting and re-commerce business models. Under these conditions, the use of virgin resources may be minimised favouring the growth of recycled alternatives. Additional reuse business models provide an incentive for higher quality of the product and repair systems, enhancing the durability of jeans. In these regards, MUD Jeans states that: "If we wash them once per week and work to maintain and repair them it's possible to make them last 2-3 years, assuming a daily use" (MUD).

The material requirements are thus assumed of 2 pairs of jeans for the analysed period of 5 years.

In these regards, the percentage parameters for sourcing, disposal and recovery will be the following, as displayed also for the potentials set in Circular Stage 2 in the general assumptions:

- *Landfill/Incineration: 10%*
- *Cascaded Recycling: 30%*
- *Closed loop: 60%*

Once again, the procedure deployed follows the principles of process, assembly and life cycle design stated for the Business-As-Usual, applying the specific flows of the scenario under investigation. These percentages where then applied to the four-fold materials flows, comprising cotton, viscose, polyester and elastane, as already unfolded. Furthermore, transport processes where included following the value chain network displayed above, adding 250 km for the reverse supply chain logistic management, according to the hypothesis of economic sustainability exposed in the structuring of flows (EURATEX, 2017). On the other hand, washing and drying electricity requirements are

computed exploiting the estimates of European averages for number of washes, temperature and type of drying process, selecting: weekly hot washes and tumbler drying (Levi Strauss & Co, 2015).

The overall results found are shown in figures 60 and 61, and will be discussed in the next section.

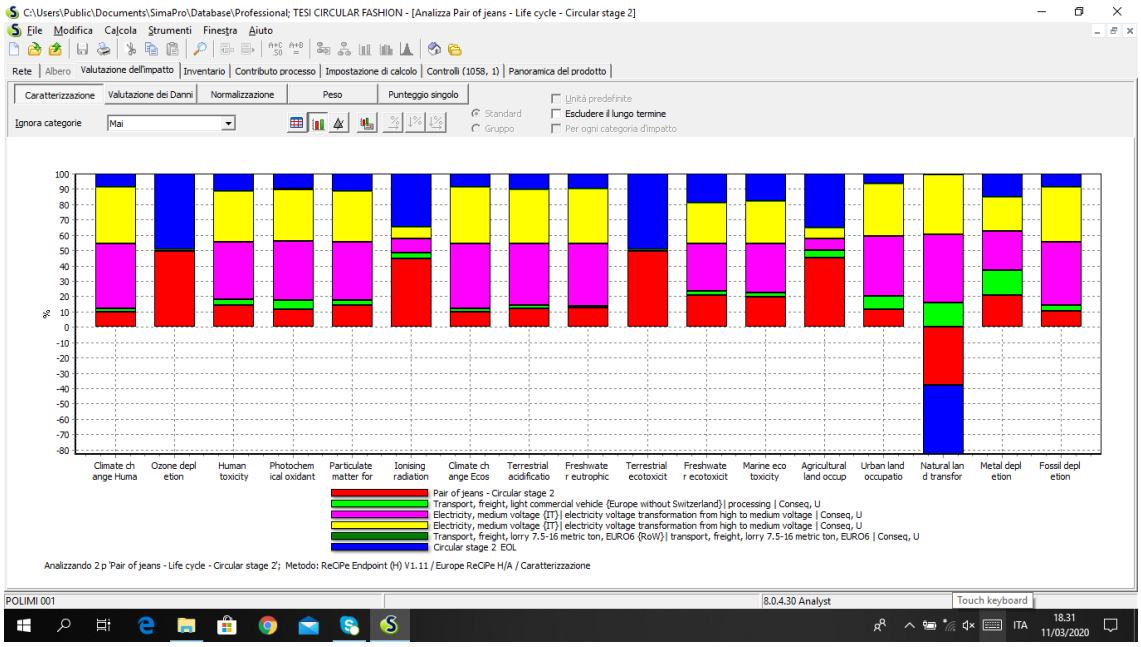


Figure. 60 - LCA Single impact categories: Circular Stage 2

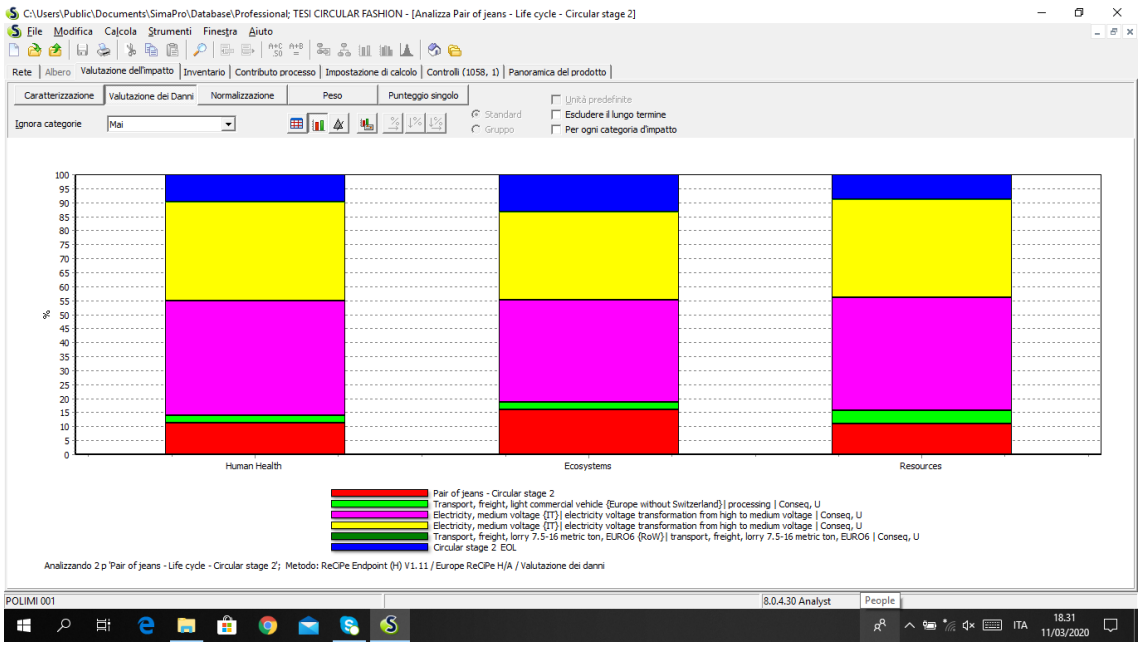


Figure. 61 - LCA integrated impact categories: Circular Stage 2

In this case, overall results start assuming a different shape. The lifetime extension through reuse business models, shows indeed how, in relative terms, use phase processes (in yellow and pink) generally dominate the total values of environmental performances. On the other side, jeans and fibres production and disposal alternatives, shrink even more in relative impacts, thanks to the higher volumes of materials held in circulation, avoiding landfilling and incineration.

CIRCULAR STAGE 3 SCENARIO

This scenario entails the application of waste prevention methods, i.e. eco-design principles and consumer awareness campaigns. Under these conditions, the use of virgin resources may be minimised favouring the growth of recycled alternatives and overall production and waste creation will decline. In addition, the improvement of durability and reusability performances, as well as the enhanced consumer care habits shall increase even more the longevity of jeans.

The material requirements are thus assumed of 1 pair of jeans for the analysed period of 5 years.

In these regards, the percentage parameters for sourcing, disposal and recovery will be the following, as displayed also for the potentials set in Circular Stage 3 in the general assumptions:

- *Landfill/Incineration: 1%*
- *Cascaded Recycling: 4%*
- *Closed loop: 95%*

These percentages where then applied to the four-fold materials flows, comprising cotton, viscose, polyester and elastane, as already unfolded. Furthermore, transport processes where included following the value chain network displayed above, adding 250 km for the reverse supply chain logistic management, according to the hypothesis of economic sustainability exposed in the structuring of flows (EURATEX, 2017). On the other hand, washing and drying electricity requirements are computed exploiting the estimates of European averages for number of washes, temperature and type of drying process, selecting: cold washes every 10 uses and line drying (Levi Strauss & Co, 2015).

The overall results found are shown in figures 62 and 63, and will be discussed in the next section.

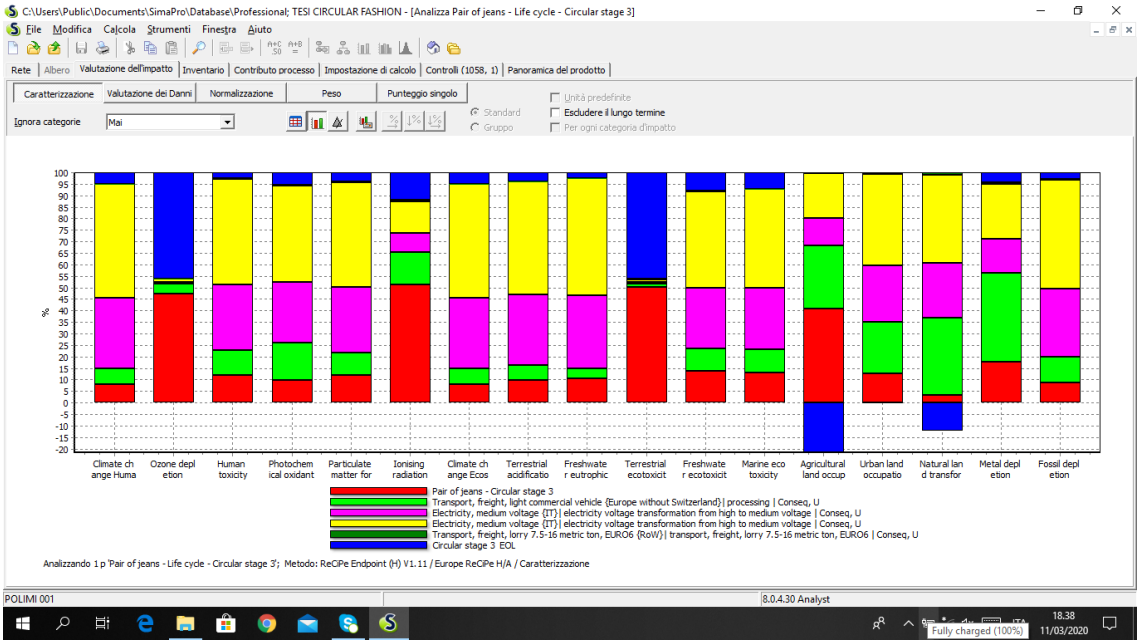


Figure. 62 - LCA Single impact categories: Circular Stage 3

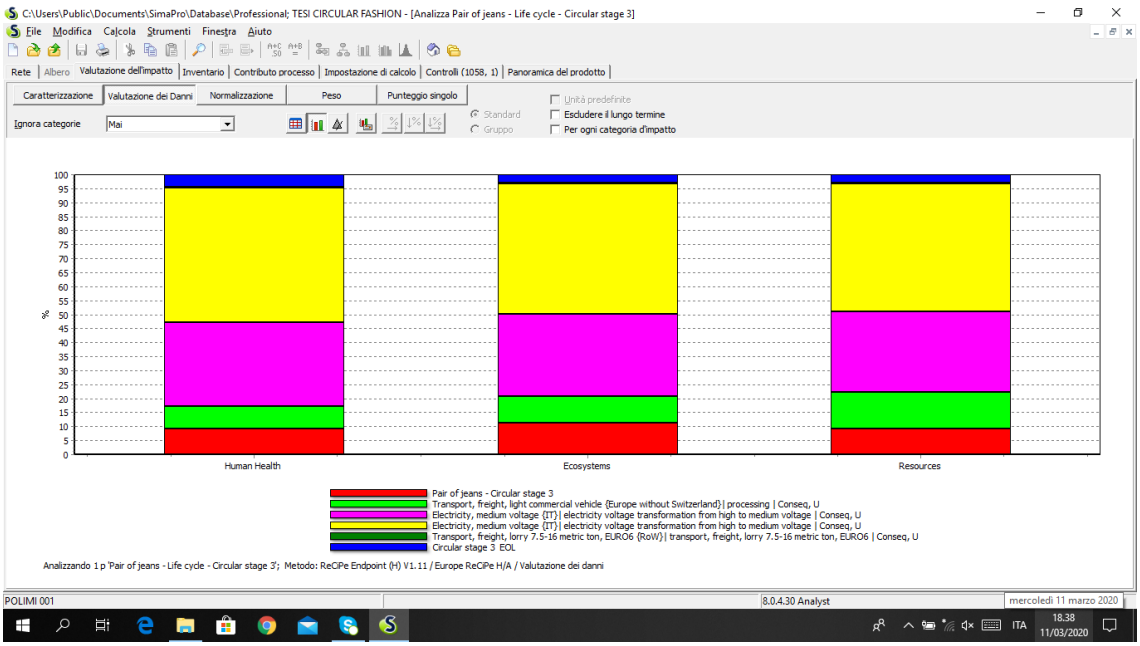


Figure. 63 - LCA integrated impact categories: Circular Stage 3

Final findings related to the full implementation of the proposed framework show how in relative terms it is possible to widely reduce the impacts of material mix and end-of-life alternatives. In particular, the additional shrinkage of volumes produced thanks to the application of eco-design principles further extends the relative weight of use phase processes, underlining the crucial prerequisite to address consumer awareness issues. Furthermore, in order to gain a more accurate evaluation of improvement it is necessary to assess absolute values of impacts, which will be unfolded in the next section within a comprehensive cross-scenario comparison.

4.4.2. Life Cycle Assessment - Discussion

According to the assumptions made for the structure of flows, it is possible to develop the aggregate comparison of the different scenarios, embodying the gradual implementation of the proposed model. As shown in figures 64 and 65, patterns tend to recur homogeneously for all impact categories.

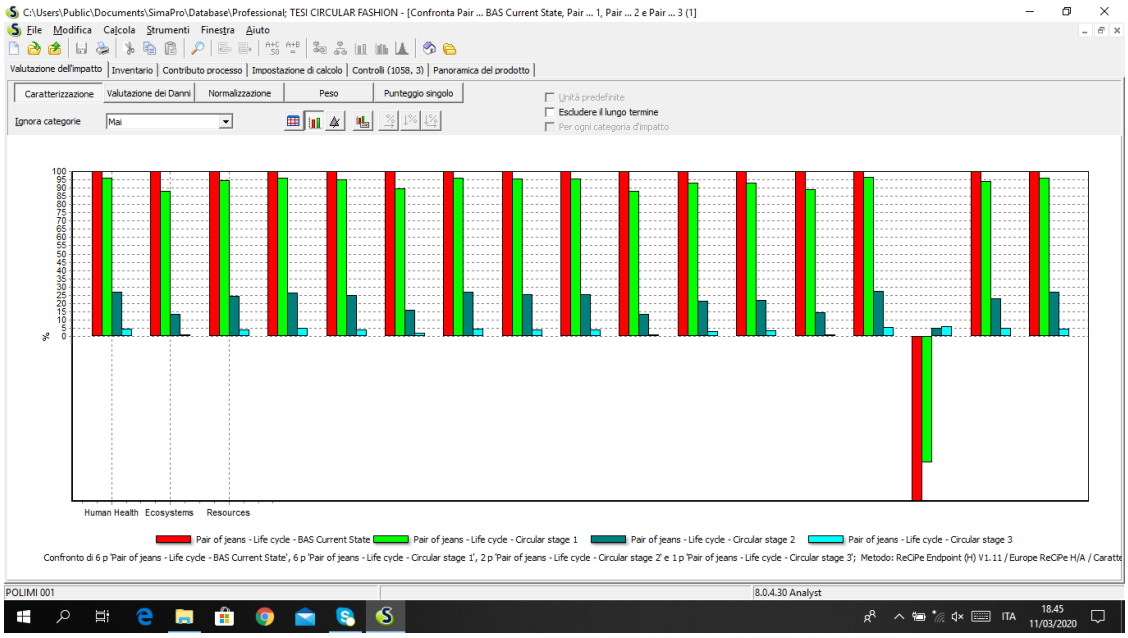


Figure. 64 - LCA Single impact categories: Cross-scenario comparison

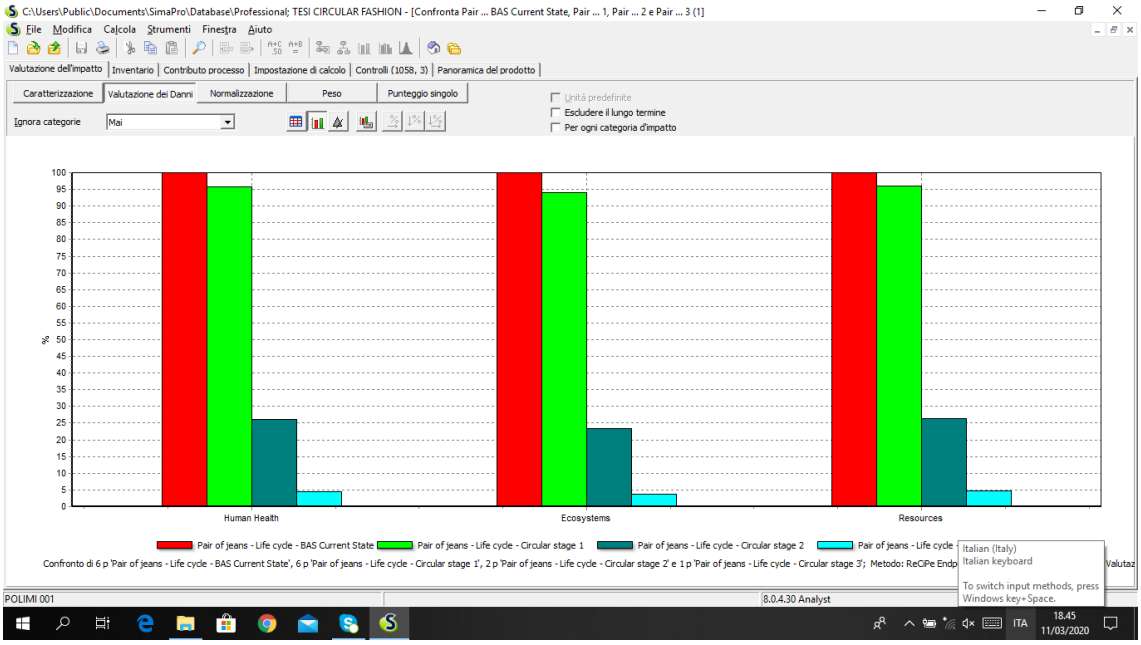


Figure. 65 - LCA Single integrated categories: Cross-scenario comparison

Looking in particular at figure 65, which displays the results for the macro-impact categories of '***Human Health***', '***Ecosystems'*** and '***Resources'***, it becomes evident how, even qualitatively, the improvement carried by the framework is significant. Specifically, the positive differential gains massive magnitude within the transition from Circular Stage 1 to Circular Stage 2, thus concretely demonstrating the potential of a more widespread application of the waste hierarchy principle of 'Reuse' throughout the fashion supply chain.

Hence, it is possible to evince how the establishment of basic product stewardship principles (Circular Stage 1 in green), which facilitate the expansion of textile-to-textile recycling but do not act much on the volumes of demand and production, provide only limited improvements in environmental performances.

The true differentiator thus appears to be the reduction in volumes produced and the enhancement of value held in circulation, in relation to higher reuse and recycling levels. In particular, Circular Stage 3 (in light blue) entails a positive differential in respect to Circular Stage 2, thanks to the application of eco-design principles and less polluting use stage habits for washing and drying. The improvements entailed in these two scenarios, do indeed outpace the worsening in polluting impacts causes by the reprocessing and additional transportation of resources.

Generally, the total outlook of results widely validates the implementation of the features of the proposed model also in this case.

4.5. INTEGRATED VALIDATION DISCUSSION

In conclusion, findings gathered from the two-fold validation procedure deployed appear to favour the complete implementation of the model, demonstrating its robustness and significance for the fashion industry current state issues resolution. In particular, the 'Financial sustainability assessment' provides the proposition of economic viability of such a model, with the related reduction in uncertainty for investors and stakeholders. On the other hand, the 'Environmental sustainability assessment' provides evidence for the potential reduction in pollution and waste creation, entailed in the structure of flows enabled by such an redistribution scheme of value and incentives.

Again, it has to be pointed out that the assumptions and limitations comprised may affect the accuracy of results. Hence, findings shall be evaluated from a qualitative standpoint, focusing on the delta of performances provided by each scenario.

Accordingly, even considering only the relative terms, outcomes still provide extensive proof of the validity of the integration of features comprised in the proposed framework. This verifies how it is crucial to exploit the synergies among innovative circular fashion business models, regulative incentive schemes and digitalisation technologies. The key game changer stays indeed in the merging of specific prevention and reuse models within a differentiated and individualised product stewardship framework, backed up by the efficiency, traceability and security enabled by the blockchain architecture.

CONCLUSIONS

This dissertation work aimed at establishing a link between regulative policies and technologies exploitation, in order to develop a framework characterised by well-aimed adaptation to the business context, concrete implementation potential, incentives effectiveness and ability to drive widespread balanced consequences throughout the whole fashion value chain. The research process thus comprised a thorough analysis of state of art and practice contributions, matched with additional concrete insights from sustainability- and circularity-oriented companies operating in the fashion ecosystem. The review and the combination of considerations gathered, supported the evolution of a framework proposals, based on the integration of three different building blocks referring to closed-loop business models, product stewardship principles and an enabling blockchain digital layer.

In particular, the novel solution was designed for the sake of resolving issues related to the scarce organic economic viability of end-of-life management infrastructures, widespread uncertainty feelings across stakeholders, unbalanced and untrusty business relationships, as well as the inability to correctly and effectively incentivise a diffused transition towards sustainable production and commercialisation behaviours.

In respect to this, the first hurdle was answered through the adoption of a comprehensive product stewardship framework and thus the subsidisation of collectors, sorters and recyclers.

Secondarily, the requirement for more trustworthy relations and collaboration was solved through the advanced traceability and reliability enabled by blockchain and by the specific definition of producer fees. As a matter of fact, since fees and costs are partly transferred among actors across the value chain, long term oriented players will strive to cooperate and co-innovate with other sustainability and circularity champions in order to achieve win-win conditions, in which all collaborators would receive a discount over the fees in relation to the improvement performance in pollution and waste minimisation.

Finally, for what regards the difficulty for incentive schemes to accomplish the effective desired outcomes, as implied in the validation testing, the framework entails a process of fees allocation according to the differentiated analysis of business conditions, organisations, competition patterns and environmental

performances, which shall facilitate the establishment of a proper fit between incentives and company requirements or expectations. This roots also in the intent to explicate fees and discounts relative to the diverse performances and amelioration actions, so that whenever a company plans to invest in a specific circular strategy it can clearly and directly link the hurdles and efforts to the receivable economic benefits.

Generally, the implementation of the model is to benefit both end-of-life management operators and direct supply chain players on the long term. The former because financially supported in the process of scaling up and optimising flows logistics and operations. The latter because provided with cheaper inputs for circular materials, as well as possibly larger customer base, higher profitability levels and a positive impact for the satisfaction of 2030 Sustainable Development Goals. Furthermore, consumers shall also play an increasingly relevant role in the amelioration of environmental performances. The model facilitates indeed their information and consciousness, on one side through the implementation of the blockchain technology and related IoT devices, on the other through a stricter relation with brands for customer support, care instructions and disposal scenarios counselling.

In conclusion, the comprehensive research evolution leads to the resolution of the stated research questions, as follows:

- ***RQ1. What are the causes for a fashion industry state in which it is now plenty of circular business model tools but there is still no wide diffusion of strategic circular approaches?***

  This first inquiry was answered through the critical analysis of the state of art and practice. Specifically, the limitation in widespread adoption of closed-loop business models and the presence of rare cases of sustainability champions, related to technical, economic, systemic and regulative stumbling blocks. The competition patterns of the fashion industry and the complexity present in the related supply network cause the loss of transparency and the diffusion of unsustainable business practices, rendering it difficult to understand where to act in order to improve systems circularity (See **Sections 1.1.2. – 1.2.4.**). The fast-fashion demand requirements as well as care and disposal habits of consumers lead to unmanageable volumes of waste, where the decline in quality translates in insufficient reusable fraction for collectors (See **Sections 1.1.1. – 1.1.4 – 1.2.4. – 2.7.**). The nature of textile fibres and the tendency to design clothing with fibre blends and aggressive finishing treatments makes recycling a complex process that needs time to be developed and optimised (See **Section 1.2.4. – 1.2.8**). Furthermore, the switch towards circular business models comprises large change

management efforts and burdensome financial requirements, especially in regards to the commercialisation gap, where informational asymmetries particularly hamper the relationship with lenders (See **Section 1.2.4**.). In respect to reverse logistics and enabling digital technologies there is also an obstacle linked to missing technical skills and competences (See **Sections 1.2.7. – 1.3.3**.). Generally, a great gap leading to uncertainty for the circular development is the lack of standardisation in terms and policies as well as the current inexistence of reverse supply chain related markets (See **Section 2.6**.). Finally, the maybe most relevant prerequisite is a top-down support scheme for the overcoming of operational hurdles (See **Sections 1.3.3. – 2.11**.).

- ***RQ2. What possible scenarios of consumption and production patterns will be enabled in the near future by the upcoming technologies?***

  This second inquiry is answered through diverse insights gathered in the 16 interviews deployed. Also in the concrete field of operating fashion supply chain companies it is rather straightforward that current production, consumptions and disposal patterns do not provide long-term persistence. The progressive shortage and price increase for virgin raw materials is widely acknowledged. Hence, it goes without saying that a strategic turnaround will be necessary. Ecosystems boundaries will demand an improvement in research efficiency which will translate for companies in sustainable sourcing, reuse business models and the transition from an economy based on the sale of goods to one based on the sale of performances. Upcoming technologies in NIR sorting, chemical fibre-to-fibre recycling and digitalisation accordingly enable a scenario where supply chain players drive the circulation of materials and provide enhanced services to more conscious consumers.

- ***RQ3. How would it be possible to effectively incentivize companies towards closed-loop developments?***

  The final inquiry is answered through the development of the model. As anticipated above, the instrument required to provide effective incentives and drive the transition of companies is a product stewardship scheme, in which subsidies, fees and discounts shall be much more extensively individualised on the specific business case. The categorisation of products and performance indicators shall thus be exhaustive and any player shall see clearly the benefits related to determined strategic actions to be implemented.

Limitations

Still, since loop-closing integration impacts both on logistics and capital investment, it is critical to balance and optimise such trade- offs to produce a more sustainable system design and operation (Walmsley *et al.*, 2019). In these regards, blockchain technology architecture and optimisation incentives shall support the efficiency and effectiveness of logistics, but the model remains slightly limited referring to concrete operational implementation, due to limited data availability.

The novelty of topics links indeed to the inability of companies to share information, either because sensible data are tapped or because they are not even informed or conscious in regards to certain topics. This drawback further developed into several hurdles.

First of all, the validity of the testing is limited by missing estimates for change managements costs, complete circular investments required (only some technologies were considered but these do not cover the overall magnitude of investments), repair service, additional operational costs for reverse logistics, consumer awareness campaigns costs and impact of cannibalisation relations among products. This last aspect is partly neutralised by the statements of Interview 6, where VF unfolds how transition to new circular business models is necessary and will in any case outpace traditional product lines providing greater value.

Secondarily, it was not possible to carry out an accurate analysis of subsidies towards recyclers. Still this limitation actually does not affect too much the results because the mechanism that drives subsidies determination is based on a yardstick competition and is thus based on the average net costs, which will be low in the case of recyclers because there are already some recycling realities that exceeded breakeven without subsidies. Accordingly, the average costs will thus be a small amount, which while also incentivising less efficient players to improve their processes, it is not characterised by a great relevance in respect to overall end-of-life management costs. Consistently, collectors and sorters are the actors with the major concrete need for subsidisation.

Furthermore, for what regards the environmental sustainability test, the life cycle assessment analysis does not include the impact of microfiber leakage connected to synthetics fibres. This issue lacks often of visibility but actually creates extreme effects on the marine environment and will thus need to be studied further with more accurate methods.

Finally, the greatest limitation lies in the assumption that economic fees allocation actually leads to the flows percentages defined among the general assumptions in **Section 4.2**. The reliability of this and all other hypothesis shall be widely tested with a more comprehensive and coherent database. This shall

serve also to understand wide implementation outcomes, since the testing ground used embodies only a very limited scope of analysis in respect to the whole fashion supply chain.

Beyond this informative limitations, given the circular economy foundation of the model, it is relevant to analyse also possible rebound effects. These were considered during the evolution of the framework principles, even though it is very complex to preview the comprised impacts.

In particular, as a common feature of complex economic systems, the rebound effect can be defined as "a behaviour or other systemic response to a measure taken to reduce environmental impacts that offsets the effect of the measure." (Hertwich, 2005). The rebound effect though, illustrates how an increase in efficiency can generate a higher than expected use of resources (Figge and Thorpe, 2019). In accordance, multiple possible rebound effect typologies were identified:

- Basic implementation of such a framework entails reduced economic viability in upstream stages, which we'll thus need to better adapt to the circular structure of the industry
- The efficiency in production may incentivise greater consumption levels, neutralising the positive sustainability performance achieved
- Fibre degradation during recycling limits the potential of circularity
- The geographical burden shifting problem is limited by blockchain but not eliminated
- The modified role and significance of trust may produce deviations in linearity of market behaviours
- Improved circularity and reverse supply chain operations may result in overarching higher transportation levels
- The overwhelming volume of big data produced may hamper analysis effectiveness and speed

Further research

Essentially, this dissertation and test aims at representing a basis of discussion for policymakers, in order to be able to reach a more accurate proposition for when the enabling technologies will be at scale in the next 3-6 years. Comprising all limitations, it shall be used as introductory reference on which to build up more concretely applicable and testable solutions, upon further research as also availability of greater and more reliable databases.

In particular, in respect to fibre degradation a parameter analysis shall be carried out within the boundaries of the life cycle assessment, in order to evaluate the potential outcomes along a defined timeline. Technicalities for the progress in technological development shall also be investigated further.

Moreover, extensive studies shall be deployed for estimating the effects on price and demand patterns of the development of markets for collectors, sorters and recyclers. More in general, the objective shall be to unfold the relations among price convenience and demanded volumes variation, also in connection to the allocation of fees and incentives, implemented in the framework. Accordingly, the design of the framework shall be adapted to further solve possible rebound effects, in particular referring to reduced economic viability in upstream stages, enhanced volumes of consumption and geographical burden shifting issues.

In conclusion, it shall be assessed if and how the model may be possibly applied to other sectors with similar fragmentation and complexity of the supply chain network.

Annex I

The fundamental structure of the questionnaire used during industrial interviews, deployed the following principal questions:

- *How deep-rooted are the current environmental macro-trends and the need for concrete circular innovation among firms throughout the fashion supply chain?*
- *Which traceability technologies do you currently use? Are you planning to implement blockchain architecture? Which characterising barriers and drivers do you find?*
- *In relation to the total yearly production, which percentage of inputs originated from open-loop and closed-loop recycling alternatives?*
- *Which percentage of outputs is sent to down-cycling, incineration or disposal?*
- *Which do you identify as the main opportunities to support circular fashion innovation, basing on economic drivers?*
- *How do you design the cooperation among stakeholders and which is degree of strategic relevance for you?*
- *Which level of effectiveness in consumer awareness campaigns do you find?*
- *Do you have instruments or methods to measure the degree of durability, reusability or recyclability of an item?*
- *Do you employ innovative chemical recycling technologies?*
- *Which level of effectiveness do you find in relation to rental and sharing programs?*
- *How is it possible to optimise the processes of reverse logistics?*
- *Which is your opinion in the present debate around extended producer responsibility schemes?*
- *Which is your opinion in regards to the significance and reliability of ecolabels?*
- *Which additional barriers do you find more pressing against the circular evolution of the industry?*
- *Do you account for the possibility to receive discounts on VAT taxes, in the measure of the materials reused?*

Annex II

The next tables reflect the computations necessary for the 'Financial Sustainability Assessment'

Collector & Sorter – Excel Spreadsheets

Business as Usual	***Year***	***0***	***1***	***2***	***3***	***4***	***5***
Quantity demanded in Humana shops		1181	1282	1383	1485	1585	1682
Quantity - Original resold		31579	33544	35640	37875	40258	42801
Quantity exported - Tropical mix		1077	1096	1113	1128	1141	1151
Quantity sent to downcycling		1137	1218	1305	1398	1497	1604
Quantity sent to closed loop recycling		23	26	28	32	35	39
Solidarity shop price		€ 33,00	€ 33,60	€ 34,20	€ 34,80	€ 35,40	€ 36,00
Original price		€ 0,53	€ 0,54	€ 0,55	€ 0,56	€ 0,57	€ 0,58
Down-cycling price		€ 0,10	€ 0,10	€ 0,10	€ 0,10	€ 0,11	€ 0,11
Closed-loop price		€ 0,17	€ 0,17	€ 0,17	€ 0,17	€ 0,18	€ 0,18
Total revenues		***€ 55.760***	***€ 61.233***	***€ 66.954***	***€ 72.906***	***€ 79.066***	***€ 85.401***
Total Operating Costs (-)		***-€ 63.787***	***-€ 69.740***	***-€ 76.546***	***-€ 83.863***	***-€ 91.711***	***-€ 100.111***
Quantity sorted		4696	5002	5327	5673	6042	6435
Quantity recovered		36127	38475	40976	43639	46476	49497
Differentiated Collection costs		€ 22.396	€ 24.326	€ 26.413	€ 28.668	€ 31.105	€ 33.737
Maximum bid		€ 3.613	€ 3.847	€ 4.098	€ 4.364	€ 4.648	€ 4.950
Sorting		€ 1.174,12	€ 1.300,45	€ 1.438,25	€ 1.588,48	€ 1.752,16	€ 1.930,39
Disposal costs		€ 372,92	€ 452,91	€ 545,15	€ 651,06	€ 772,24	€ 910,46
Personnel costs		€ 11.359,74	€ 12.546,13	€ 13.838,84	€ 15.246,65	€ 16.779,06	€ 18.446,08
Leasing costs		€ 2.260,14	€ 2.019,47	€ 2.150,73	€ 2.290,54	€ 2.439,44	€ 2.598,00
Other operating costs		€ 3.447,18	€ 3.785,47	€ 4.139,16	€ 4.507,15	€ 4.887,95	€ 5.279,61
Services		€ 19.164,82	€ 21.462,49	€ 23.923,71	€ 26.546,99	€ 29.328,24	€ 32.259,73
EBITDA		-€ 8.027	-€ 8.508	-€ 9.592	-€ 10.956	-€ 12.646	-€ 14.710
Discount Rate	**0,0604**						
NPV	-51.623,93 €						

Circular Stage 1	***Year***	***0***	***1***	***2***	***3***	***4***	***5***
Quantity demanded in Humana shops		2101	2409	2600	2790	2978	3162
Quantity - Original resold		55874	61792	64605	67449	70313	73742
Quantity exported - Tropical mix		1916	2060	2092	2121	2144	2163
Quantity sent to downcycling		2064	2430	2703	3000	3324	4368
Quantity sent to closed loop recycling		313	1255	2381	3736	5352	6702
Solidarity shop price		€ 33,00	€ 33,60	€ 34,20	€ 34,80	€ 35,40	€ 36,00
Original price		€ 0,53	€ 0,54	€ 0,55	€ 0,56	€ 0,57	€ 0,58
Down-cycling price		€ 0,10	€ 0,10	€ 0,10	€ 0,10	€ 0,11	€ 0,11
Closed-loop price		€ 0,73	€ 0,74	€ 0,75	€ 0,76	€ 0,77	€ 0,78
Total revenues		***€ 99.272,41***	***€ 115.343,77***	***€ 126.332,46***	***€ 137.803,09***	***€ 149.715,39***	***€ 161.984,17***
Total operational costs		***-€ 117.431,57***	***-€ 136.940,95***	***-€ 150.886,79***	***-€ 165.918,46***	***-€ 182.084,90***	***-€ 199.168,43***
Quantity sorted manually		8356	9401	10012	10663	11356	12094
Quantity recovered		64279	72314	77014	82020	87351	93029
Differentiated Collection costs		€ 43.443	€ 50.361	€ 55.220	€ 60.498	€ 66.228	€ 72.448
Maximum bid		€ 6.427,92	€ 7.231,37	€ 7.701,41	€ 8.202,04	€ 8.735,13	€ 9.302,94
Sorting		€ 2.089,07	€ 2.444,20	€ 2.703,20	€ 2.985,54	€ 3.293,14	€ 3.628,15
Disposal costs		€ 650,07	€ 762,76	€ 841,28	€ 921,43	€ 1.002,13	€ 828,76
Personnel costs		€ 20.211,94	€ 23.580,47	€ 26.010,11	€ 28.656,08	€ 31.535,86	€ 34.669,20
Leasing costs		€ 4.021,37	€ 4.669,70	€ 5.128,39	€ 5.627,00	€ 6.168,70	€ 6.757,11
Other operating costs		€ 6.137,14	€ 7.130,69	€ 7.810,02	€ 8.519,15	€ 9.255,59	€ 10.014,06
Services		€ 34.119,82	€ 40.428,89	€ 45.140,69	€ 50.177,61	€ 55.534,57	€ 61.188,42
Blockchain OPEX		€ 331,49	€ 331,49	€ 331,49	€ 331,49	€ 331,49	€ 331,49
EBITDA		-€ 18.159,15	-€ 21.597,18	-€ 24.554,33	-€ 28.115,38	-€ 32.369,51	-€ 37.184,25
Investments		**€ 2.883,51**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**
Fees		-	-	-	-	-	-
Subsidies		*€ 21.043*	*€ 21.597*	*€ 24.554*	*€ 28.115*	*€ 32.370*	*€ 37.184*
Discounts		-	-	-	-	-	-
Discount Rate	0,0604						
NPV	**0,00 €**						

Circular Stage 2	Year	0	1	2	3	4	5
Quantity demanded in Humana shops		1537,20	1821,75	2032,73	2256,38	2491,92	2738,18
Quantity - Original resold		40877,34	42296,34	41142,35	39697,05	37939,84	35853,39
Quantity exported - Tropical mix		1401,91	1557,57	1635,73	1714,82	1794,15	1872,89
Quantity sent to downcycling		1509,69	1540,56	1474,23	1394,94	1301,94	1194,62
Quantity sent to closed loop recycling		229,28	3260,69	6581,09	10208,75	14143,57	18378,72
Solidarity shop price		€ 33,00	€ 33,60	€ 34,20	€ 34,80	€ 35,40	€ 36,00
Original price		€ 0,53	€ 0,59	€ 0,61	€ 0,63	€ 0,65	€ 0,66
Down-cycling price		€ 0,10	€ 0,11	€ 0,11	€ 0,12	€ 0,12	€ 0,12
Closed-loop price		€ 0,73	€ 0,79	€ 0,81	€ 0,83	€ 0,85	€ 0,86
Total revenues		***€ 72.627,32***	***€ 88.936,76***	***€ 100.065,93***	***€ 112.038,30***	***€ 124.836,52***	***€ 138.422,12***
Total operational costs (-)		***-€ 85.937,08***	***-€ 101.193,51***	***-€ 111.564,39***	***-€ 122.657,31***	***-€ 134.452,43***	***-€ 146.911,11***
Quantity sorted		6113	6792	7133	7478	7824	8167
Quantity recovered		47026	52248	54870	57523	60184	62825
Differentiated Collection costs		€ 31.783	€ 36.387	€ 39.342	€ 42.429	€ 45.631	€ 48.926
Maximum bid		€ 4.702,64	€ 5.224,80	€ 5.486,97	€ 5.752,30	€ 6.018,41	€ 6.282,52
Sorting		€ 1.528,36	€ 1.765,98	€ 1.925,93	€ 2.093,84	€ 2.268,94	€ 2.450,18
Disposal costs		€ 475,59	€ 466,13	€ 415,59	€ 349,23	€ 265,58	€ 163,26
Personnel costs		€ 14.786,98	€ 17.037,32	€ 18.531,24	€ 20.097,25	€ 21.727,89	€ 23.413,05
Leasing costs		€ 2.942,02	€ 3.373,94	€ 3.653,79	€ 3.946,36	€ 4.250,17	€ 4.563,26
Other operating costs		€ 4.489,91	€ 5.498,18	€ 6.186,20	€ 6.926,34	€ 7.717,54	€ 8.557,42
Services		€ 24.961,93	€ 31.173,02	€ 35.755,22	€ 40.796,00	€ 46.306,15	€ 52.288,01
Blockchain OPEX		€ 267,11	€ 267,11	€ 267,11	€ 267,11	€ 267,11	€ 267,11
EBITDA		-€ 13.309,76	-€ 12.256,76	-€ 11.498,47	-€ 10.619,01	-€ 9.615,91	-€ 8.488,99
Investments		**€ 2.215,58**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**
Fees		-	-	-	-	-	-
Subsidies		*€ 15.525*	*€ 12.257*	*€ 11.498*	*€ 10.619*	*€ 9.616*	*€ 8.489*
Discounts		-	-	-	-	-	-
Discount Rate	0,0604						
NPV	**0,00 €**						

Circular Stage 3	Year	0	1	2	3	4	5
Quantity demanded in Humana shops		1018,95	1263,92	1476,68	1717,44	1989,23	2295,42
Quantity - Original resold		27095,96	27302,83	25932,86	24527,25	23103,53	21683,45
Quantity exported - Tropical mix		929,27	1080,63	1188,27	1305,23	1432,22	1570,04
Quantity sent to downcycling		1000,72	885,01	702,15	508,90	305,79	93,56
Quantity sent to closed loop recycling		151,98	3262,24	6517,30	9916,26	13446,56	17092,58
Solidarity shop price		€ 33,00	€ 33,66	€ 34,33	€ 35,02	€ 35,72	€ 36,43
Original price		€ 0,53	€ 0,54	€ 0,55	€ 0,56	€ 0,57	€ 0,58
Down-cycling price		€ 0,10	€ 0,10	€ 0,10	€ 0,11	€ 0,11	€ 0,11
Closed-loop price		€ 0,73	€ 0,74	€ 0,75	€ 0,76	€ 0,77	€ 0,78
Total revenues		***€ 48.141,75***	***€ 59.746,40***	***€ 69.900,83***	***€ 81.480,47***	***€ 94.667,00***	***€ 109.666,32***
Total costs (-)		***-€ 56.981,63***	***-€ 67.911,77***	***-€ 76.603,89***	***-€ 86.377,24***	***-€ 97.365,39***	***-€ 109.721,04***
Quantity sorted		4052	4557	4850	5163	5495	5847
Quantity recovered		31172	35051	37310	39712	42266	44980
Differentiated Collection costs		€ 21.067	€ 24.411	€ 26.752	€ 29.292	€ 32.045	€ 35.029
Maximum bid		€ 3.117,19	€ 3.505,15	€ 3.731,01	€ 3.971,20	€ 4.226,56	€ 4.498,05
Sorting		€ 1.013,09	€ 1.184,74	€ 1.309,58	€ 1.445,52	€ 1.593,41	€ 1.754,24
Disposal costs		€ 315,25	€ 288,14	€ 233,69	€ 169,28	€ 94,63	€ 9,59
Personnel costs		€ 9.801,70	€ 11.429,79	€ 12.600,79	€ 13.874,50	€ 15.258,87	€ 16.762,85
Leasing costs		€ 1.950,15	€ 2.263,47	€ 2.484,49	€ 2.724,44	€ 2.984,77	€ 3.267,12
Other operating costs		€ 2.976,18	€ 3.693,59	€ 4.321,35	€ 5.037,22	€ 5.852,43	€ 6.779,70
Services		€ 16.546,27	€ 20.941,58	€ 24.976,73	€ 29.669,12	€ 35.115,24	€ 41.425,70
Blockchain OPEX		€ 194,42	€ 194,42	€ 194,42	€ 194,42	€ 194,42	€ 194,42
EBITDA		-€ 8.839,87	-€ 8.165,38	-€ 6.703,07	-€ 4.896,77	-€ 2.698,39	-€ 54,72
Investments		**€ 1.543,49**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**
Fees							
Subsidies		*€ 10.383*	*€ 8.165*	*€ 6.703*	*€ 4.897*	*€ 2.698*	*€ 55*
Discounts							
Discount Rate	0,0604						
NPV	**0,00 €**						

Retail Brand – Excel Spreadsheets

Business-As-Usual	***Year***	***0***	***1***	***2***	***3***	***4***	***5***
Quantity demanded		51282	54615	58165	61946	65973	70261
Normal selling price	€	131	€ 133	€ 136	€ 138	€ 140	€ 143
Discounted price	€	100	€ 102	€ 104	€ 106	€ 107	€ 109
Revenues from traditional sales	€	2.685.126	€ 2.911.635	€ 3.156.266	€ 3.420.410	€ 3.705.571	€ 4.013.308
Revenues from discounted sales	€	1.540.591	€ 1.670.551	€ 1.810.907	€ 1.962.460	€ 2.126.072	€ 2.302.636
Total revenues	€	4.225.716	€ 4.582.185	€ 4.967.173	€ 5.382.871	€ 5.831.643	€ 6.315.944
Total Costs (-)	-€	3.573.197	-€ 3.940.171	-€ 4.342.270	-€ 4.782.663	-€ 5.264.802	-€ 5.792.354
Quantity produced		66667	70999,5	75614,5	80529,8	85764,9	91339,3
Textile input costs	€	946.000	€ 1.025.801	€ 1.111.987	€ 1.205.048	€ 1.305.513	€ 1.413.932
Total Production costs	€	1.576.667	€ 1.709.668	€ 1.853.311	€ 2.008.413	€ 2.175.856	€ 2.356.554
Disposal costs	€	4.684,41	€ 5.230,73	€ 5.828,34	€ 6.481,56	€ 7.195,10	€ 7.973,93
Selling, general and administrative costs	€	1.991.846	€ 2.225.272	€ 2.483.130	€ 2.767.769	€ 3.081.751	€ 3.427.827
EBITDA	€	652.519	€ 642.015	€ 624.903	€ 600.207	€ 566.841	€ 523.589
Discount Rate							
0,0604							
NPV							
2.976.155,75 €							

Circular Stage 1	***Year***	***0***	***1***	***2***	***3***	***4***	***5***
Quantity demanded		51282	57692	61442	65436	69689	74219
Normal selling price	€	131	€ 134	€ 136	€ 139	€ 142	€ 145
Discounted price	€	100,14	€ 102,14	€ 104,18	€ 106,27	€ 108,39	€ 110,56
Revenues from traditional sales	€	2.685.125,52	€ 3.081.168,18	€ 3.347.074,09	€ 3.635.941,58	€ 3.949.704,07	€ 4.290.575,96
Revenues from discounted sales	€	1.540.590,77	€ 1.767.820,24	€ 1.920.383,76	€ 2.086.121,48	€ 2.266.142,71	€ 2.461.717,96
Revenues from online sales							
Total revenues	€	4.225.716,29	€ 4.848.988,43	€ 5.267.457,84	€ 5.722.063,06	€ 6.215.846,78	€ 6.752.293,92
Total operational costs (-)	-€	3.600.737,26	-€ 4.193.897,02	-€ 4.624.668,29	-€ 5.098.127,40	-€ 5.618.338,30	-€ 6.189.913,44
Quantity produced		66667	75000	79875	85067	90596	96485
Textile input costs	€	946.000,00	€ 1.083.594,22	€ 1.174.635,87	€ 1.272.939,60	€ 1.379.047,75	€ 1.493.583,16
Total Production costs	€	1.576.666,67	€ 1.805.990,37	€ 1.957.726,45	€ 2.121.565,99	€ 2.298.412,91	€ 2.489.305,26
Disposal costs	€	4.684,41	€ 5.525,43	€ 6.156,71	€ 6.846,73	€ 7.600,37	€ 8.423,13
Selling, general and administrative costs	€	1.991.846,18	€ 2.354.841,22	€ 2.633.245,14	€ 2.942.174,68	€ 3.284.785,02	€ 3.664.645,05
Blockchain OPEX		27.540 €	27.540 €	27.540 €	27.540 €	27.540 €	27.540 €
EBITDA	€	624.979,03	€ 655.091,40	€ 642.789,55	€ 623.935,67	€ 597.508,48	€ 562.380,48
Investments for blockchain infrastructure		**118.728 €**					
Fees	€	*17.659*	€ *18.124*	€ *20.605*	€ *23.594*	€ *27.164*	€ *31.204*
Subsidies							
Discounts		-	-	-	-	-	-
	€	607.320,52	€ 636.967,57	€ 622.184,14	€ 600.341,91	€ 570.344,76	€ 531.176,34
Discount Rate							
0,0604							
NPV							
2.816.091,01 €							

Circular Stage 2	Year	0	1	2	3	4	5
Quantity demanded		51282	57692	61442	65436	69689	74219
Normal selling price		€ 130,90	€ 133,28	€ 135,66	€ 138,04	€ 140,42	€ 142,80
Resale		€ 163,90	€ 166,88	€ 169,86	€ 172,84	€ 175,82	€ 178,80
Rental price		€ 99,00	€ 100,80	€ 102,60	€ 104,40	€ 106,20	€ 108,00
Discounted price		€ 100,14	€ 101,96	€ 103,78	€ 105,60	€ 107,42	€ 109,24
Closed-loop selling price		€ 0,73	€ 0,74	€ 0,75	€ 0,76	€ 0,77	€ 0,78
Open-loop selling price		€ 0,10	€ 0,10	€ 0,10	€ 0,11	€ 0,11	€ 0,11
Revenues from traditional sales		€ 3.473.881,14	€ 3.831.031,59	€ 3.975.628,69	€ 4.096.292,77	€ 4.184.257,45	€ 4.228.937,22
Revenues from extra new product sales		€ 63.038,40	€ 76.385,16	€ 87.108,92	€ 98.645,65	€ 110.766,60	€ 123.085,22
Revenues from rental		€ 1.269.229,50	€ 1.712.726,80	€ 2.028.235,47	€ 2.434.480,44	€ 2.921.189,46	€ 3.504.238,49
Revenues from discounted sales		€ 1.155.443,08	€ 1.276.032,19	€ 1.326.247,35	€ 1.368.828,78	€ 1.400.842,44	€ 1.418.716,60
Revenues from closed-loop sales		€ 705,39	€ 1.449,13	€ 2.261,75	€ 3.196,12	€ 4.266,73	€ 5.489,77
Revenues from open-loop sales		€ 521,20	€ 538,11	€ 519,41	€ 493,47	€ 459,18	€ 415,31
Total revenues		€ 5.962.818,71	€ 6.898.162,97	€ 7.420.001,59	€ 8.001.937,22	€ 8.621.781,87	€ 9.280.882,61
Total operational costs (-)		-€ 4.395.181,46	-€ 5.101.150,40	-€ 5.534.030,29	-€ 6.004.633,49	-€ 6.500.410,38	-€ 7.019.579,68
Quantity produced		50000	54232	55378	56170	56509	56277
Quantity recovered with RL		17949	20192	21505	22903	24391	25977
Textile input costs		€ 815.924,18	€ 901.079,03	€ 936.538,81	€ 966.607,99	€ 989.214,66	€ 1.001.836,62
Total Production costs		€ 1.359.873,64	€ 1.501.798,38	€ 1.560.898,02	€ 1.611.013,31	€ 1.648.691,10	€ 1.669.727,70
Disposal costs		€ 2.499,59	€ 2.534,43	€ 2.370,88	€ 2.143,50	€ 1.846,32	€ 1.473,99
Selling, general and administrative costs		€ 2.810.651,93	€ 3.349.993,26	€ 3.709.319,31	€ 4.114.442,09	€ 4.556.209,46	€ 5.036.975,72
Discounting (rewards)		€ 179.487,00	€ 201.922,00	€ 215.047,00	€ 229.026,00	€ 243.911,50	€ 259.766,50
Reverse logistic costs		€ 15.129,30	€ 17.362,34	€ 18.855,08	€ 20.468,59	€ 22.212,01	€ 24.095,77
Blockchain OPEX		€ 27.540,00	€ 27.540,00	€ 27.540,00	€ 27.540,00	€ 27.540,00	€ 27.540,00
EBITDA		€ 1.567.637,25	€ 1.797.012,57	€ 1.885.971,29	€ 1.997.303,73	€ 2.121.371,49	€ 2.261.302,93
Investments for blockchain infrastructure		€ 118.728,00					
Fees		*€ 12.985*	*€ 10.284*	*€ 9.684*	*€ 8.980*	*€ 8.170*	*€ 7.252*
Subsidies							
Discounts		*€ 4.673,29*	*€ 7.839,35*	*€ 10.921,90*	*€ 14.613,70*	*€ 18.993,38*	*€ 23.952,14*
		€ 1.554.652,03	€ 1.786.728,08	€ 1.876.287,79	€ 1.988.323,68	€ 2.113.201,15	€ 2.254.050,93
Discount Rate							
0,0604							
NPV							
9.244.057,36 €							

Circular Stage 3	Year	0	1	2	3	4	5
Quantity demanded		51282	57692	61442	65436	69689	74219
Normal selling price		€ 130,90	€ 133,28	€ 135,66	€ 138,04	€ 140,42	€ 142,80
Resale		€ 163,90	€ 166,88	€ 169,86	€ 172,84	€ 175,82	€ 178,80
Rental price		€ 99,00	€ 100,80	€ 102,60	€ 104,40	€ 106,20	€ 108,00
Discounted price		€ 100,14	€ 101,96	€ 103,78	€ 105,60	€ 107,42	€ 109,24
Closed-loop selling price		€ 0,73	€ 0,74	€ 0,75	€ 0,76	€ 0,77	€ 0,78
Open-loop selling price		€ 0,10	€ 0,10	€ 0,10	€ 0,11	€ 0,11	€ 0,11
Revenues from traditional sales		€ 3.473.881	€ 3.831.032	€ 3.975.629	€ 4.096.293	€ 4.184.257	€ 4.228.937
Revenues from extra new product sales		€ 63.038,40	€ 76.385,16	€ 87.108,92	€ 98.645,65	€ 110.766,60	€ 123.085,22
Revenues from rental		€ 1.269.229,50	€ 1.610.271,41	€ 1.933.386,17	€ 2.320.631,02	€ 2.784.585,43	€ 3.340.362,49
Revenues from discounted sales		€ 1.155.443,08	€ 1.276.032,19	€ 1.326.247,35	€ 1.368.828,78	€ 1.400.842,44	€ 1.418.716,60
Revenues from closed-loop sales		€ 705,39	€ 1.449,13	€ 2.261,75	€ 3.196,12	€ 4.266,73	€ 5.489,77
Revenues from open-loop sales		€ 521,20	€ 538,11	€ 519,41	€ 493,47	€ 459,18	€ 415,31
Total revenues		€ 5.962.818,71	€ 6.795.707,58	€ 7.325.152,28	€ 7.888.087,80	€ 8.485.177,84	€ 9.117.006,61
Total Costs		***-€ 4.069.812,11***	***-€ 4.697.967,11***	***-€ 5.121.619,89***	***-€ 5.571.345,99***	***-€ 6.046.216,48***	***-€ 6.544.706,16***
Quantity produced		38462	41717	42598	43208	43469	43290
Quantity recovered with RL		17948,7	20192,2	21504,7	22902,6	24391,15	25976,65
Textile input costs		€ 654.922,42	€ 723.274,14	€ 751.736,84	€ 775.872,63	€ 794.018,46	€ 804.149,80
Total Production costs		€ 1.091.537,37	€ 1.205.456,89	€ 1.252.894,74	€ 1.293.121,05	€ 1.323.364,09	€ 1.340.249,66
Disposal costs		€ 546,51	€ 528,60	€ 459,70	€ 367,44	€ 248,28	€ 98,27
Selling, general and administrative costs		€ 2.810.651,93	€ 3.300.237,28	€ 3.661.903,37	€ 4.055.902,91	€ 4.484.020,61	€ 4.948.035,96
Discounting (rewards)		€ 179.487,00	€ 201.922,00	€ 215.047,00	€ 229.026,00	€ 243.911,50	€ 259.766,50
Reverse logistic costs		€ 15.129,30	€ 17.362,34	€ 18.855,08	€ 20.468,59	€ 22.212,01	€ 24.095,77
Blockchain OPEX		27.540,00 €	27.540,00 €	27.540,00 €	27.540,00 €	27.540,00 €	27.540,00 €
EBITDA		€ 1.893.006,60	€ 2.097.740,47	€ 2.203.532,40	€ 2.316.741,81	€ 2.438.961,36	€ 2.572.300,45
Investments for blockchain infrastructure		**118.728,00 €**					
Fees		*€ 9.733*	*€ 7.657*	*€ 6.289*	*€ 4.597*	*€ 2.535*	*€ 51*
Subsidies							
Discounts		*€ 7.925,90*	*€ 10.466,54*	*€ 14.316,10*	*€ 18.996,54*	*€ 24.628,76*	*€ 31.152,69*
		€ 1.883.273,99	€ 2.090.083,18	€ 2.197.243,08	€ 2.312.144,60	€ 2.436.426,39	€ 2.572.249,00
Discount Rate							
0,0604							
NPV							
10.813.914,91 €							

Fabric Producer – Excel Spreadsheets

Business as usual	***Year***	***0***	***1***	***2***	***3***	***4***	***5***
Quantity demanded		100000	106499	113422	120795	128647	137009
Normal selling price		€ 9,46	€ 9,63	€ 9,80	€ 9,98	€ 10,15	€ 10,32
Total revenues		**€ 946.000**	**€ 1.025.801**	**€ 1.111.987**	**€ 1.205.048**	**€ 1.305.513**	**€ 1.413.932**
Total Costs (-)		**-€ 820.533,67**	**-€ 905.005,17**	**-€ 997.478,75**	**-€ 1.098.666,48**	**-€ 1.209.343,67**	**-€ 1.330.333,26**
Quantity produced		112000	119279,16	127032,36	135290,064	144085,032	153450,024
Textile input costs		€ 257.805	€ 281.024	€ 306.162	€ 333.370	€ 362.810	€ 394.650
Virgin material costs		€ 254.095	€ 277.260	€ 302.364	€ 329.563	€ 359.021	€ 390.911
Recycled materials costs		€ 3.710	€ 3.764	€ 3.798	€ 3.807	€ 3.789	€ 3.738
Total Production costs		€ 374.230	€ 407.934	€ 444.425	€ 483.920	€ 526.655	€ 572.874
Textile Fibres Disposal costs		€ 1.926	€ 2.131	€ 2.355	€ 2.599	€ 2.865	€ 3.154
Leasing costs		€ 118.785	€ 128.806	€ 139.628	€ 151.313	€ 163.928	€ 177.542
Personnel costs		€ 325.592	€ 366.134	€ 411.071	€ 460.834	€ 515.896	€ 576.763
EBITDA		*€ 125.466,33*	*€ 120.795,61*	*€ 114.508,09*	*€ 106.381,44*	*€ 96.169,64*	*€ 83.599,11*
Discount Rate	0,0604						
NPV	**536.446,74 €**						

Circular Stage 1	***Year***	***0***	***1***	***2***	***3***	***4***	***5***
Quantity demanded		100000	112499,4	119811,9	127600,2	135893,55	144727,05
Normal selling price		€ 9,46	€ 9,63	€ 9,80	€ 9,98	€ 10,15	€ 10,32
Revenues from traditional sales		€ 946.000,00	€ 1.083.594,22	€ 1.174.635,87	€ 1.272.939,60	€ 1.379.047,75	€ 1.493.583,16
Total revenues		***€ 946.000,00***	***€ 1.083.594,22***	***€ 1.174.635,87***	***€ 1.272.939,60***	***€ 1.379.047,75***	***€ 1.493.583,16***
Total operational costs (-)		***-€ 817.827,06***	***-€ 954.329,87***	***-€ 1.052.611,54***	***-€ 1.159.314,23***	***-€ 1.275.052,73***	***-€ 1.400.658,31***
Quantity produced		112000	125999,328	134189,328	142912,224	152200,776	162094,296
Textile input costs		€ 256.995,08	€ 296.989,44	€ 324.119,08	€ 352.909,59	€ 383.398,62	€ 415.724,31
Price of virgin material		€ 254.002,60	€ 285.665,91	€ 303.781,19	€ 322.660,14	€ 342.296,13	€ 366.855,85
Price of recycled material		€ 2.992,49	€ 11.323,53	€ 20.337,89	€ 30.249,45	€ 41.102,49	€ 48.868,46
Total production costs		€ 373.054,31	€ 431.110,16	€ 470.491,57	€ 512.283,91	€ 556.541,80	€ 603.465,81
Disposal costs		€ -	€ -	€ -	€ -	€ -	€ -
Leasing costs		€ 118.785,46	€ 136.062,62	€ 147.494,36	€ 159.837,97	€ 173.161,55	€ 187.543,30
Personnel costs		€ 325.592,17	€ 386.761,97	€ 434.230,49	€ 486.797,24	€ 544.954,26	€ 609.254,08
Blockchain OPEX		395,12 €	395,12 €	395,12 €	395,12 €	395,12 €	395,12 €
EBITDA		*€ 128.172,94*	*€ 129.264,35*	*€ 122.024,33*	*€ 113.625,36*	*€ 103.995,02*	*€ 92.924,85*
Investments for blockchain infrastructure		**€ 1.703,40**					
Fees		*€ 2.602*	*€ 2.671*	*€ 3.037*	*€ 3.477*	*€ 4.003*	*€ 4.599*
Subsidies							
Discounts	-	-	-	-	-	-	-
		€ 125.570,63	€ 126.593,46	€ 118.987,75	€ 110.148,39	€ 99.991,94	€ 88.326,34
Discount Rate	0,0604						
NPV	**552.909,95 €**						

Circular Stage 2	***Year***	***0***	***1***	***2***	***3***	***4***	***5***
Quantity demanded		75000	81348	83066	84255	84764	84415
Normal selling price		€ 10,88	€ 11,08	€ 11,27	€ 11,47	€ 11,67	€ 11,87
Closed-loop selling price		€ 0,73	€ 0,74	€ 0,75	€ 0,76	€ 0,77	€ 0,78
Revenues from traditional sales		€ 815.924,18	€ 901.079,03	€ 936.538,81	€ 966.607,99	€ 989.214,66	€ 1.001.836,62
Revenues from closed-loop sales		€ -	€ -	€ -	€ -	€ -	€ -
Total revenues		***€ 815.924,18***	***€ 901.079,03***	***€ 936.538,81***	***€ 966.607,99***	***€ 989.214,66***	***€ 1.001.836,62***
Total operational costs (-)		***-€ 663.367,43***	***-€ 750.482,77***	***-€ 795.635,59***	***-€ 834.295,48***	***-€ 864.224,29***	***-€ 882.825,83***
Quantity produced		84000	91110	93034	94366	94936	94545
Textile input costs		€ 192.746,12	€ 217.290,07	€ 228.385,01	€ 236.270,66	€ 240.290,43	€ 239.779,36
Price of virgin material		€ 190.501,76	€ 186.464,49	€ 168.579,98	€ 147.606,17	€ 123.710,80	€ 97.261,83
Price of recycled material		€ 2.244,36	€ 30.825,58	€ 59.805,03	€ 88.664,50	€ 116.579,63	€ 142.517,53
Total production costs		€ 279.790,45	€ 315.418,48	€ 331.523,90	€ 342.970,72	€ 348.805,82	€ 348.063,95
Disposal costs		€ -	€ -	€ -	€ -	€ -	€ -
Leasing costs		€ 102.452,36	€ 113.144,91	€ 117.597,46	€ 121.373,12	€ 124.211,75	€ 125.796,64
Personnel costs		€ 280.822,97	€ 321.617,72	€ 346.212,57	€ 369.649,98	€ 390.905,06	€ 408.663,58
Blockchain OPEX		€ 301,65	€ 301,65	€ 301,65	€ 301,65	€ 301,65	€ 301,65
EBITDA		€ 152.556,75	€ 150.596,26	€ 140.903,23	€ 132.312,50	€ 124.990,37	€ 119.010,79
Investments for blockchain infrastructure		**€ 1.300,46**					
Fees		*€ 1.964,38*	*€ 1.516,89*	*€ 1.386,85*	*€ 1.242,63*	*€ 1.085,69*	*€ 918,28*
Subsidies							
Discounts		*€ 637,93*	*€ 1.153,99*	*€ 1.649,74*	*€ 2.234,34*	*€ 2.917,39*	*€ 3.680,22*
		€ 150.592	€ 149.079	€ 139.516	€ 131.070	€ 123.905	€ 118.093
Discount Rate	0,0604						
NPV	**669.442,04 €**						

Circular Stage 3	Year	0	1	2	3	4	5
Quantity demanded		57692	62576	63897	64812	65203	64935
Normal selling price		€ 11,35	€ 11,56	€ 11,76	€ 11,97	€ 12,18	€ 12,38
Closed-loop selling price		€ 0,73	€ 0,74	€ 0,75	€ 0,76	€ 0,77	€ 0,78
Revenues from traditional sales		€ 654.922,42	€ 723.274,14	€ 751.736,84	€ 775.872,63	€ 794.018,46	€ 804.149,80
Revenues from closed-loop sales		€ -	€ -	€ -	€ -	€ -	€ -
Total revenues		***654922***	***723274***	***751737***	***775873***	***794018***	***804150***
Total operational costs (-)		***-€ 501.489,03***	***-€ 570.129,58***	***-€ 607.599,11***	***-€ 640.757,38***	***-€ 667.889,50***	***-€ 686.947,76***
Quantity produced		58269	63201	64536	65460	65855	65584
Textile input costs		€ 133.704,38	€ 152.520,12	€ 162.270,67	€ 170.065,51	€ 175.433,85	€ 177.866,87
Price of virgin material		€ 132.147,51	€ 118.963,58	€ 95.227,64	€ 68.583,08	€ 39.428,92	€ 8.433,59
Price of recycled material		€ 1.556,87	€ 33.556,54	€ 67.043,02	€ 101.482,43	€ 136.004,93	€ 169.433,28
Total production costs		€ 194.085,41	€ 221.398,35	€ 235.552,25	€ 246.867,25	€ 254.659,94	€ 258.191,72
Disposal costs		€ -	€ -	€ -	€ -	€ -	€ -
Leasing costs		€ 82.236,01	€ 90.818,66	€ 94.392,61	€ 97.423,24	€ 99.701,74	€ 100.973,90
Personnel costs		€ 225.409,74	€ 258.154,69	€ 277.896,38	€ 296.709,02	€ 313.769,95	€ 328.024,28
Blockchain OPEX		€ 242,13	€ 242,13	€ 242,13	€ 242,13	€ 242,13	€ 242,13
EBITDA		€ 153.433,40	€ 153.144,56	€ 144.137,73	€ 135.115,25	€ 126.128,95	€ 117.202,03
Investments for blockchain infrastructure		**€ 1.043,85**					
Fees		*€ 220,66*	*€ 170,27*	*€ 136,82*	*€ 97,55*	*€ 52,29*	*€ 1,03*
Subsidies							
Discounts		*€ 2.381,65*	*€ 2.500,61*	*€ 2.899,77*	*€ 3.379,42*	*€ 3.950,78*	*€ 4.597,48*
		€ 153.212,74	€ 152.974,29	€ 144.000,91	€ 135.017,69	€ 126.076,66	€ 117.201,01
Discount Rate	0,0604						
NPV	**683.509,90 €**						

Fibre Producer – Excel Spreadsheets

Business as usual	Year	0	1	2	3	4	5
Quantity demanded (tons)		11,71	12,47	13,28	14,15	15,07	16,05
Normal selling price		€ 3,59	€ 3,66	€ 3,74	€ 3,81	€ 3,89	€ 3,96
Recycled Lyocell selling price		€ 5,39	€ 5,13	€ 4,86	€ 4,57	€ 4,28	€ 3,96
Total revenues		***€ 42.259,63***	***€ 45.888,86***	***€ 49.809,74***	***€ 54.044,57***	***€ 58.617,46***	***€ 63.553,41***
Total operative costs (-)		***-€ 33.796,39***	***-€ 37.364,10***	***-€ 41.267,77***	***-€ 45.536,79***	***-€ 50.203,13***	***-€ 55.300,64***
Quantity produced (tons)		11,83	12,60	13,42	14,29	15,22	16,21
Cost of material and other purchased services		€ 19.728,72	€ 21.713,73	€ 23.873,61	€ 26.222,64	€ 28.776,28	€ 31.550,76
Personnel Costs		€ 8.968,61	€ 10.113,40	€ 11.384,09	€ 12.793,11	€ 14.354,04	€ 16.081,50
Other Operating expenses		€ 5.099,06	€ 5.536,97	€ 6.010,06	€ 6.521,04	€ 7.072,81	€ 7.668,38
EBITDA		€ 8.463,24	€ 8.524,76	€ 8.541,98	€ 8.507,78	€ 8.414,33	€ 8.252,77
Discount Rate	0,0604						
NPV	**41.536 €**						

Circular Stage 1	Year	0	1	2	3	4	5
Quantity demanded (tons)		11,71	13,18	14,03	14,94	15,92	16,95
Normal selling price		€ 3,59	€ 3,66	€ 3,74	€ 3,81	€ 3,89	€ 3,96
Recycled Lyocell selling price		€ 5,39	€ 5,13	€ 4,86	€ 4,57	€ 4,28	€ 3,96
Revenues from traditional sales		€ 41.628,89	€ 46.639,55	€ 49.416,03	€ 52.303,47	€ 55.300,42	€ 59.077,52
Revenues from Recycled Lyocell sales		€ 630,74	€ 2.298,18	€ 3.955,38	€ 5.606,39	€ 7.212,56	€ 8.056,03
Total revenues		€ 42.259,63	€ 48.937,73	€ 53.371,41	€ 57.909,86	€ 62.512,98	€ 67.133,55
Total operative costs (-)		***-€ 33.783,20***	***-€ 39.069,94***	***-€ 43.371,72***	***-€ 47.870,55***	***-€ 52.534,42***	***-€ 57.313,53***
Quantity produced (tons)		11,83	13,31	14,17	15,09	16,07	17,12
Virgin (tons)		11,71	12,86	13,35	13,86	14,37	15,07
Refibra (tons)		0,12	0,45	0,82	1,24	1,70	2,05
Virgin - Cost of material and other purchased services		€ 19.531,43	€ 21.440,07	€ 23.011,18	€ 24.655,61	€ 26.373,33	€ 28.488,28
Refibra - Cost of material and other purchased services		€ 295,93	€ 1.091,81	€ 1.901,49	€ 2.725,68	€ 3.544,31	€ 3.999,37
Personnel Costs		€ 8.968,61	€ 10.785,33	€ 12.198,11	€ 13.708,07	€ 15.307,96	€ 16.987,41
Other Operating expenses		€ 4.844,11	€ 5.609,60	€ 6.117,83	€ 6.638,06	€ 7.165,70	€ 7.695,34
Blockchain OPEX		143,12 €	143,12 €	143,12 €	143,12 €	143,12 €	143,12 €
EBITDA		*€ 8.476,43*	*€ 9.867,80*	*€ 9.999,69*	*€ 10.039,31*	*€ 9.978,56*	*€ 9.820,02*
Investments for blockchain infrastructure		**€ 617,01**					
Fees		*€ 165*	*€ 169*	*€ 192*	*€ 220*	*€ 253*	*€ 291*
Subsidies							
Discounts	-	-	-	-	-	-	-
		€ 8.311,69	€ 9.698,72	€ 9.807,46	€ 9.819,20	€ 9.725,15	€ 9.528,91
Discount Rate	0,0604						
NPV	**45.793,60 €**						

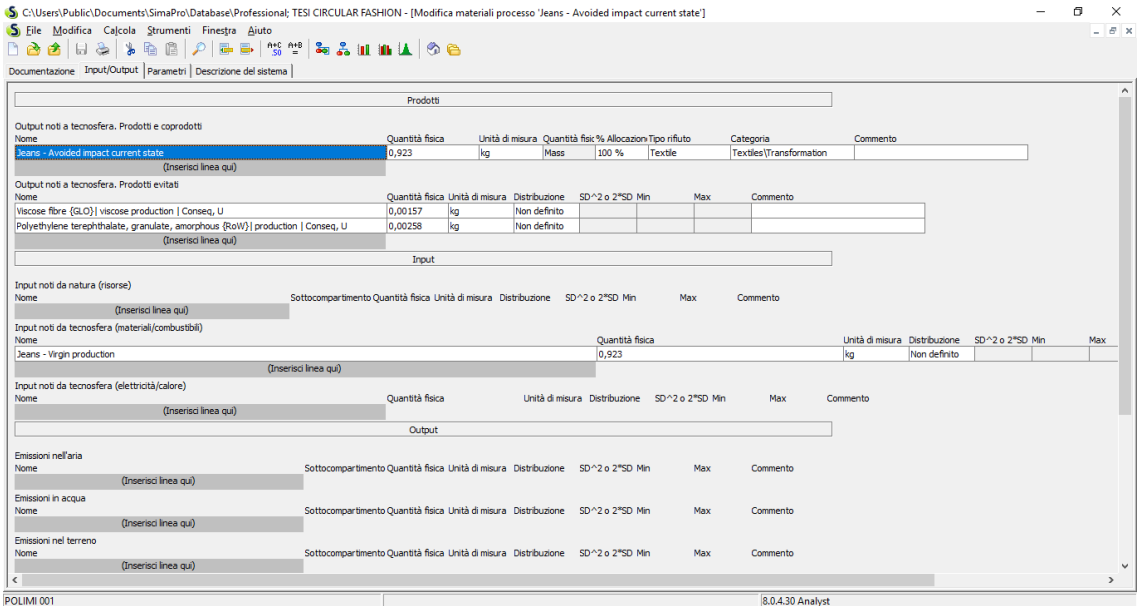
Circular Stage 2	Year	0	1	2	3	4	5
Quantity demanded		8,78	9,53	9,73	9,87	9,93	9,89
Normal selling price		€ 3,59	€ 3,66	€ 3,74	€ 3,81	€ 3,89	€ 3,96
Recycled Lyocell selling price		€ 5,39	€ 5,13	€ 4,86	€ 4,57	€ 4,28	€ 3,96
Revenues from traditional sales		€ 31.222	€ 30.443	€ 27.423	€ 23.927	€ 19.986	€ 15.663
Revenues from Recycled Lyocell sales		€ 473,06	€ 6.256,24	€ 11.631,08	€ 16.432,94	€ 20.457,10	€ 23.494,19
Total revenues		€ 31.694,69	€ 36.699,57	€ 39.053,96	€ 40.360,02	€ 40.443,47	€ 39.156,99
Total operative costs (-)		-€ 25.328,03	-€ 29.827,95	-€ 32.275,05	-€ 33.900,15	-€ 34.511,81	-€ 33.933,99
Quantity produced		8,87	9,62	9,83	9,97	10,03	9,99
Virgin		8,78	8,39	7,41	6,34	5,19	3,99
Refibra		0,09	1,23	2,42	3,63	4,83	5,99
Virgin - Cost of material and other purchased services		€ 14.648,56	€ 14.462,82	€ 13.183,11	€ 11.632,73	€ 9.821,45	€ 7.775,71
Refibra - Cost of material and other purchased services		€ 221,95	€ 2.972,18	€ 5.591,46	€ 7.989,27	€ 10.052,77	€ 11.663,57
Personnel Costs		€ 6.726	€ 8.088	€ 8.926	€ 9.554	€ 9.904	€ 9.908
Other Operating expenses		€ 3.633	€ 4.207	€ 4.477	€ 4.626	€ 4.636	€ 4.488
Blockchain OPEX		98 €	98 €	98 €	98 €	98 €	98 €
EBITDA		€ 6.366,66	€ 6.871,62	€ 6.778,91	€ 6.459,87	€ 5.931,66	€ 5.222,99
Investments for blockchain infrastructure		**€ 422,47**					
Fees		*€ 122*	*€ 96*	*€ 90*	*€ 82*	*€ 74*	*€ 65*
Subsidies							
Discounts		*€ 42,79*	*€ 73,11*	*€ 102,53*	*€ 137,61*	*€ 179,07*	*€ 225,84*
		€ 6.244,71	€ 6.775,66	€ 6.689,20	€ 6.377,38	€ 5.857,32	€ 5.157,73
Discount Rate	0,0604						
NPV	**30.142,65 €**						

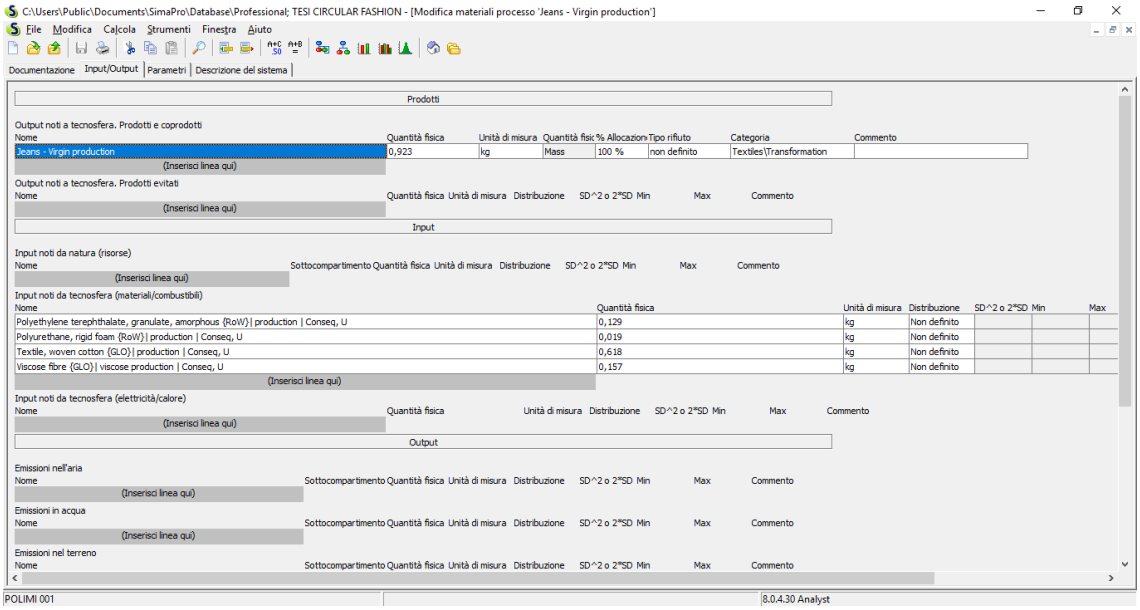
Circular Stage 3	Year	0	1	2	3	4	5
Quantity demanded		6,09	6,61	6,75	6,85	6,89	6,86
Normal selling price		€ 3,59	€ 3,66	€ 3,74	€ 3,81	€ 3,89	€ 3,96
Recycled Lyocell selling price		€ 5,39	€ 5,50	€ 5,61	€ 5,72	€ 5,83	€ 5,94
Revenues from traditional sales		€ 21.657,87	€ 19.422,72	€ 15.490,66	€ 11.117,37	€ 6.370,03	€ 1.358,12
Revenues from Recycled Lyocell sales		€ 328,15	€ 7.192,70	€ 14.607,64	€ 22.469,62	€ 30.592,19	€ 38.706,52
Total revenues		€ 21.986,02	€ 26.615,42	€ 30.098,31	€ 33.586,99	€ 36.962,21	€ 40.064,64
Total operative costs (-)		-€ 17.501,61	-€ 21.333,08	-€ 23.862,06	-€ 25.944,81	-€ 27.442,71	-€ 28.215,10
Quantity produced		6,15	6,68	6,82	6,91	6,96	6,93
Virgin		6,09	5,35	4,19	2,95	1,66	0,35
Refibra		0,06	1,32	2,63	3,97	5,30	6,58
Virgin - Cost of material and other purchased services		€ 10.161,43	€ 9.227,22	€ 7.446,89	€ 5.404,98	€ 3.130,28	€ 674,23
Refibra - Cost of material and other purchased services		€ 153,96	€ 3.189,26	€ 6.086,07	€ 8.739,32	€ 11.024,37	€ 12.810,43
Personnel Costs		€ 4.666,01	€ 5.865,74	€ 6.879,01	€ 7.950,51	€ 9.051,18	€ 10.137,92
Other Operating expenses		€ 2.520,20	€ 3.050,86	€ 3.450,09	€ 3.849,99	€ 4.236,88	€ 4.592,51
Blockchain OPEX		€ 81,58	€ 81,58	€ 81,58	€ 81,58	€ 81,58	€ 81,58
EBITDA		€ 4.484,41	€ 5.282,34	€ 6.236,25	€ 7.642,19	€ 9.519,51	€ 11.849,55
Investments for blockchain infrastructure		**€ 351,70**					
Fees		*€ 90*	*€ 70*	*€ 57*	*€ 41*	*€ 23*	*€ 0*
Subsidies							
Discounts		*€ 74,78*	*€ 98,87*	*€ 135,09*	*€ 178,76*	*€ 230,87*	*€ 290,66*
		€ 4.394,45	€ 5.212,13	€ 6.179,10	€ 7.600,84	€ 9.496,96	€ 11.849,10
Discount Rate	0,0604						
NPV	**35.039,01 €**						

Annex III

The next figures aim to show the main procedural steps for the development of the LCA assessment of the case study analysed, within the Software Simapro, representing the body of the 'Environmental Sustainability Test'.

Current State – LCA Design & Findings





C:\Users\Public\Documents\SimaPro\Database\Professional; TESI CIRCULAR FASHION - [Modifica assemblaggio 'Pair of jeans - Current state']

File Modifica Calcola Strumenti Finestra Aiuto

Input/Output | Parametri

Nome: Pair of jeans - Current state

Immagine

Commento

Stato: Nessuno

Materiali/assemblaggi	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Jeans - Avoided impact current state	0,923	kg	Non definito				
(Inserisci linea qui)							

Processi	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Spinning, bast fibre {RoW}| processing | Conseq, U	0,304	kg	Non definito				
Weaving, bast fibre {RoW}| processing | Conseq, U	0,304	kg	Non definito				
Transport, freight train {RoW}| electricity | Conseq, U	6128	kgkm	Non definito				
Transport, freight, light commercial vehicle {Europe without S	101	kgkm	Non definito				
(Inserisci linea qui)							

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File Modifica Calcola Strumenti Finestra Aiuto

Input/Output | Parametri

Nome: Pair of jeans - Life cycle - BAS Curri

Immagine

Commento

Stato: Nessuno

Assemblaggio	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Pair of jeans - Current state	1	p	Non definito				

Processi	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Transport, freight, light commercial vehicle {Europe without S	987,61	kgkm	Non definito				
Electricity, medium voltage {IT}| electricity voltage transform	61,2	kWh	Non definito				UK/France average for washing
Electricity, medium voltage {IT}| electricity voltage transform	53,3	kWh	Non definito				Uk/France average for line and drying
(Inserisci linea qui)							

Scenario smaltimento/fine vita: Current state EOL

Commento

Cicli di vita supplementari	Numero	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)						

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File Modifica Calcola Strumenti Finestra Aiuto

Documentazione | Input/Output | Parametri | Descrizione del sistema

Prodotti

Specifica del rifiuto

Nome	Quantità fisica	Unità di misura	Categoria	Commento
Current State Waste Scenario	0,923	kg	Altri	

Input

Input noti da tecnosfera (materiali/combustibili)

Nome	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max
Jeans - Avoided impact current state	0,923	kg	Non definito			
(Inserisci linea qui)						

Input noti da tecnosfera (elettricità/calore)

Nome	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)							

Output

I tipi di materiale e/o rifiuto sono separati dallo stream rifiuto

Scenario/processo di smaltimento	Tipo di Materiale / Rifiuto	Percentuale	Commento
PET (waste treatment) {GLO}| recycling of PET | Conseq, U	Textile, woven cotton {GLO}| market for | Conseq, U	12 %	
(Inserisci linea qui)			

Flussi di rifiuto rimasti dopo la separazione

Scenario/processo di smaltimento	Percentuale	Commento
Waste textile, soiled {RoW}| treatment of, municipal incineration | Cons	100 %	
(Inserisci linea qui)		

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File Modifica Calcola Strumenti Finestra Aiuto

Rete | Albero | Valutazione dell'impatto | Inventario | Contributo processo | Impostazione di calcolo | Controlli (1058, 0) | Panoramica del prodotto

Caratterizzazione | Valutazione dei Danni | Normalizzazione | Peso | Punteggio singolo

Ignora categorie: Mai

Standard / Gruppo — Unità predefinite / Escludere il lungo termine / Per ogni categoria d'impatto

Sele	Categoria d'impatto	Unità	Totale	Pair of jeans - Current state	Transport, freight, light commercial vehicle {Europe without Switzerland}| processing | Conseq, U	Electricity, medium voltage {IT}| electricity voltage transformation from high to medium voltage | Conseq,	Electricity, medium v transformation from
☑	Climate change Human Health	DALY	0,000781	0,000138	1,53E-5	0,000265	0,000231
☑	Ozone depletion	DALY	2,23E-6	1,11E-6	5,16E-9	3,77E-9	3,29E-9
☑	Human toxicity	DALY	0,000122	2,92E-5	3,24E-6	3,38E-5	2,94E-5
☑	Photochemical oxidant formation	DALY	6,04E-8	1,2E-8	2,8E-9	1,84E-8	1,6E-8
☑	Particulate matter formation	DALY	0,000278	6,46E-5	6,8E-6	7,86E-5	6,85E-5
☑	Ionising radiation	DALY	6,63E-7	3,16E-7	1,16E-8	2,83E-8	2,46E-8
☑	Climate change Ecosystems	species.yr	4,42E-6	7,81E-7	8,64E-8	1,5E-6	1,31E-6
☑	Terrestrial acidification	species.yr	1,85E-8	3,87E-9	3,18E-10	5,73E-9	4,99E-9
☑	Freshwater eutrophication	species.yr	1,04E-8	2,21E-9	1,13E-10	3,25E-9	2,83E-9
☑	Terrestrial ecotoxicity	species.yr	2,7E-7	1,35E-7	2,16E-10	4,42E-10	3,85E-10
☑	Freshwater ecotoxicity	species.yr	7,42E-9	2,32E-9	1,33E-10	1,45E-9	1,26E-9
☑	Marine ecotoxicity	species.yr	1,34E-9	4,04E-10	2,64E-11	2,79E-10	2,43E-10
☑	Agricultural land occupation	species.yr	1,58E-6	7,6E-7	3,06E-8	5,41E-8	4,71E-8
☑	Urban land occupation	species.yr	1,12E-7	2,1E-8	8,11E-9	3,58E-8	3,11E-8
☑	Natural land transformation	species.yr	-4,95E-8	-4,41E-8	6,61E-9	1,87E-8	1,63E-8
☑	Metal depletion	$	1,33	0,398	0,151	0,234	0,204
☑	Fossil depletion	$	20,4	3,76	0,647	6,72	5,85

Analizzando 6 p 'Pair of jeans - Life cycle - BAS Current State'; Metodo: ReCiPe Endpoint (H) V1.11 / Europe ReCiPe H/A / Caratterizzazione

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File Modifica Calcola Strumenti Finestra Aiuto

Rete | Albero | Valutazione dell'impatto | Inventario | Contributo processo | Impostazione di calcolo | Controlli (1058, 0) | Panoramica del prodotto

Caratterizzazione | Valutazione dei Danni | Normalizzazione | Peso | Punteggio singolo

Ignora categorie: Mai

Standard / Gruppo — Unità predefinite / Escludere il lungo termine / Per ogni categoria d'impatto

Sele	Categoria di danno	Unità	Totale	Pair of jeans - Current state	Transport, freight, light commercial vehicle {Europe without Switzerland}| processing | Conseq, U	Electricity, medium voltage {IT}| electricity voltage transformation from high to medium voltage | Conseq,	Electricity, medium v transformation from
☑	Human Health	DALY	0,00118	0,000233	2,53E-5	0,000378	0,000329
☑	Ecosystems	species.yr	6,38E-6	1,66E-6	1,33E-7	1,62E-6	1,41E-6
☑	Resources	$	21,7	4,15	0,798	6,95	6,05

Circular Stage 1 – LCA Design & Findings

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File Modifica Calcola Strumenti Finestra Aiuto

Documentazione | Input/Output | Parametri | Descrizione del sistema

Prodotti

Output noti a tecnosfera. Prodotti e coprodotti

Nome	Quantità fisica	Unità di misura	Quantità fisic	% Allocazion	Tipo rifiuto	Categoria	Commento
Jeans - Avoided impact circular stage 1	0,923	kg	Mass	100 %	non definito	Textiles\Transformation	
(Inserisci linea qui)							

Output noti a tecnosfera. Prodotti evitati

Nome	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Viscose fibre {GLO}| viscose production | Conseq, U	0,019	kg	Non definito				
Textile, woven cotton {GLO}| production | Conseq, U	0,074	kg	Non definito				
Polyethylene terephthalate, granulate, amorphous {RoW}| production | Conseq, U	0,015	kg	Non definito				
Polyurethane, flexible foam {RoW}| production | Conseq, U	0,00228	kg	Non definito				
(Inserisci linea qui)							

Input

Input noti da natura (risorse)

Nome	Sottocompartimento	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)								

Input noti da tecnosfera (materiali/combustibili)

Nome	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max
Jeans - Virgin production	0,923	kg	Non definito			
(Inserisci linea qui)						

Input noti da tecnosfera (elettricità/calore)

Nome	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)							

Output

Emissioni nell'aria

Nome	Sottocompartimento	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)								

Emissioni in acqua

Nome	Sottocompartimento	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)								

Emissioni nel terreno

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File Modifica Calcola Strumenti Finestra Aiuto

Input/Output | Parametri

Nome: Pair of jeans - Circular stage 1

Immagine

Commento

Stato: Nessuno

Materiali/assemblaggi	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Jeans - Avoided impact circular stage 1	0,923	kg	Non definito				
(Inserisci linea qui)							

Processi	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Spinning, bast fibre {RoW}| processing | Conseq, U	0,304	kg	Non definito				
Weaving, bast fibre {RoW}| processing | Conseq, U	0,304	kg	Non definito				
Transport, freight train {RoW}| electricity | Conseq, U	6128	kgkm	Non definito				
Transport, freight, light commercial vehicle {Europe without S	101	kgkm	Non definito				
(Inserisci linea qui)							

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File Modifica Calcola Strumenti Finestra Aiuto

Input/Output | Parametri

Nome: Pair of jeans - Life cycle - Circular s

Immagine

Commento

Stato: Nessuno

Assemblaggio	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Pair of jeans - Circular stage 1	1	p	Non definito				

Processi	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Transport, freight, light commercial vehicle {Europe without S	987,61	kgkm	Non definito				
Electricity, medium voltage {IT}| electricity voltage transform	61,2	kWh	Non definito				UK/France average for washing (x6)
Electricity, medium voltage {IT}| electricity voltage transform	53,3	kWh	Non definito				Uk/France average for line and drying (x6)
Transport, freight, lorry 7.5-16 metric ton, EURO6 {RoW}| tr	230,75	kgkm	Non definito				
(Inserisci linea qui)							

Scenario smaltimento/fine vita: Circular stage 1 EOL

Commento

Cicli di vita supplementari	Numero	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)						

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File Modifica Calcola Strumenti Finestra Aiuto

Documentazione | Input/Output | Parametri | Descrizione del sistema

Prodotti

Specifica del rifiuto

Nome	Quantità fisica	Unità di misura	Categoria	Commento
Circular stage 1 - Waste Scenario	0,923	kg	Altri	

Input

Input noti da tecnosfera (materiali/combustibili)

Nome	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max
Jeans - Avoided impact circular stage 1	0,923	kg	Non definito			
(Inserisci linea qui)						

Input noti da tecnosfera (elettricità/calore)

Nome	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)							

Output

I tipi di materiale e/o rifiuto sono separati dallo stream rifiuto

Scenario/processo di smaltimento	Tipo di Materiale / Rifiuto	Percentuale	Commento
PET (waste treatment) {GLO}| recycling of PET | Conseq, U	Textile, woven cotton {GLO}| market for | Conseq, U	60,16 %	
(Inserisci linea qui)			

Flussi di rifiuto rimasti dopo la separazione

Scenario/processo di smaltimento	Percentuale	Commento
Waste textile, soiled {RoW}| treatment of, municipal incineration | Cons	100 %	
(Inserisci linea qui)		

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File Modifica Calcola Strumenti Finestra Aiuto

Rete | Albero | Valutazione dell'impatto | Inventario | Contributo processo | Impostazione di calcolo | Controlli (1058, 1) | Panoramica del prodotto

Caratterizzazione | Valutazione dei Danni | Normalizzazione | Peso | Punteggio singolo

Ignora categorie: Mai

Standard / Gruppo — Unità predefinite / Escludere il lungo termine / Per ogni categoria d'impatto

Sele	Categoria d'impatto	Unità	Totale	Pair of jeans - Circular stage 1	Transport, freight, light commercial vehicle {Europe without Switzerland}| processing | Conseq, U	Electricity, medium voltage {IT}| electricity voltage transformation from high to medium voltage | Conseq,	Electricity, medium v transformation from
☑	Climate change Human Health	DALY	0,000751	0,000123	1,53E-5	0,000265	0,000231
☑	Ozone depletion	DALY	1,96E-6	9,76E-7	5,16E-9	3,77E-9	3,29E-9
☑	Human toxicity	DALY	0,000116	2,6E-5	3,24E-6	3,38E-5	2,94E-5
☑	Photochemical oxidant formation	DALY	5,79E-8	1,07E-8	2,8E-9	1,84E-8	1,6E-8
☑	Particulate matter formation	DALY	0,000264	5,76E-5	6,8E-6	7,86E-5	6,85E-5
☑	Ionising radiation	DALY	5,95E-7	2,81E-7	1,16E-8	2,83E-8	2,46E-8
☑	Climate change Ecosystems	species.yr	4,25E-6	6,95E-7	8,64E-8	1,5E-6	1,31E-6
☑	Terrestrial acidification	species.yr	1,77E-8	3,44E-9	3,18E-10	5,73E-9	4,99E-9
☑	Freshwater eutrophication	species.yr	9,92E-9	1,96E-9	1,13E-10	3,25E-9	2,83E-9
☑	Terrestrial ecotoxicity	species.yr	2,38E-7	1,19E-7	2,16E-10	4,42E-10	3,85E-10
☑	Freshwater ecotoxicity	species.yr	6,88E-9	2,06E-9	1,33E-10	1,45E-9	1,26E-9
☑	Marine ecotoxicity	species.yr	1,25E-9	3,58E-10	2,64E-11	2,79E-10	2,43E-10
☑	Agricultural land occupation	species.yr	1,4E-6	6,71E-7	3,06E-8	5,41E-8	4,71E-8
☑	Urban land occupation	species.yr	1,08E-7	1,89E-8	8,11E-9	3,58E-8	3,11E-8
☑	Natural land transformation	species.yr	-3,8E-8	-3,84E-8	6,61E-9	1,87E-8	1,63E-8
☑	Metal depletion	$	1,25	0,357	0,151	0,234	0,204
☑	Fossil depletion	$	19,6	3,35	0,647	6,72	5,85

Analizzando 6 p 'Pair of jeans - Life cycle - Circular stage 1'; Metodo: ReCiPe Endpoint (H) V1.11 / Europe ReCiPe H/A / Caratterizzazione

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File Modifica Calcola Strumenti Finestra Aiuto

Rete | Albero | Valutazione dell'impatto | Inventario | Contributo processo | Impostazione di calcolo | Controlli (1058, 1) | Panoramica del prodotto

Caratterizzazione | Valutazione dei Danni | Normalizzazione | Peso | Punteggio singolo

Ignora categorie: Mai

Standard / Gruppo — Unità predefinite / Escludere il lungo termine / Per ogni categoria d'impatto

Sele	Categoria di danno	Unità	Totale	Pair of jeans - Circular stage 1	Transport, freight, light commercial vehicle {Europe without Switzerland}| processing | Conseq, U	Electricity, medium voltage {IT}| electricity voltage transformation from high to medium voltage | Conseq,	Electricity, medium v transformation from
☑	Human Health	DALY	0,00113	0,000208	2,53E-5	0,000378	0,000329
☑	Ecosystems	species.yr	6E-6	1,47E-6	1,33E-7	1,62E-6	1,41E-6
☑	Resources	$	20,9	3,71	0,798	6,95	6,05

Circular Stage 2 – LCA Design & Findings

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File Modifica Calcola Strumenti Finestra Aiuto

Documentazione | Input/Output | Parametri | Descrizione del sistema

Prodotti

Output noti a tecnosfera. Prodotti e coprodotti

Nome	Quantità fisica	Unità di misura	Quantità fisic	% Allocazion	Tipo rifiuto	Categoria	Commento
Jeans - Avoided impact circular stage 2	0,923	kg	Mass	100 %	non definito	Textiles\Transformation	
(Inserisci linea qui)							

Output noti a tecnosfera. Prodotti evitati

Nome	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Viscose fibre {GLO}| viscose production | Conseq, U	0,0942	kg	Non definito				
Textile, woven cotton {GLO}| production | Conseq, U	0,3708	kg	Non definito				
Polyethylene terephthalate, granulate, amorphous {RoW}| production | Conseq, U	0,0774	kg	Non definito				
Polyurethane, flexible foam {RoW}| production | Conseq, U	0,0114	kg	Non definito				
(Inserisci linea qui)							

Input

Input noti da natura (risorse)

Nome	Sottocompartimento	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)								

Input noti da tecnosfera (materiali/combustibili)

Nome	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max
Jeans - Virgin production	0,923	kg	Non definito			
(Inserisci linea qui)						

Input noti da tecnosfera (elettricità/calore)

Nome	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)							

Output

Emissioni nell'aria

Nome	Sottocompartimento	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)								

Emissioni in acqua

Nome	Sottocompartimento	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)								

Emissioni nel terreno

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File Modifica Calcola Strumenti Finestra Aiuto

Input/Output | Parametri

Nome: Pair of jeans - Circular stage 2

Immagine

Commento

Stato: Nessuno

Materiali/assemblaggi	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Jeans - Avoided impact circular stage 2	0,923	kg	Non definito				
(Inserisci linea qui)							

Processi	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Spinning, bast fibre {RoW}| processing | Conseq, U	0,304	kg	Non definito				
Weaving, bast fibre {RoW}| processing | Conseq, U	0,304	kg	Non definito				
Transport, freight train {RoW}| electricity | Conseq, U	6128	kgkm	Non definito				
Transport, freight, light commercial vehicle {Europe without S	101	kgkm	Non definito				
(Inserisci linea qui)							

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File Modifica Calcola Strumenti Finestra Aiuto

Input/Output | Parametri

Nome: Pair of jeans - Life cycle - Circular st

Immagine

Commento

Stato: Nessuno

Assemblaggio	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Pair of jeans - Circular stage 2	1	p	Non definito				

Processi	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Transport, freight, light commercial vehicle {Europe without S	987,61	kgkm	Non definito				
Electricity, medium voltage {IT}| electricity voltage transform	61,2	kWh	Non definito				UK/France average for washing
Electricity, medium voltage {IT}| electricity voltage transform	53,3	kWh	Non definito				Uk/France average for line and drying
Transport, freight, lorry 7.5-16 metric ton, EURO6 {RoW}| tr	230,75	kgkm	Non definito				
(Inserisci linea qui)							

Scenario smaltimento/fine vita: Circular stage 2 EOL

Commento

Cicli di vita supplementari	Numero	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)						

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File Modifica Calcola Strumenti Finestra Aiuto

Documentazione | Input/Output | Parametri | Descrizione del sistema

Prodotti

Specifica del rifiuto

Nome	Quantità fisica	Unità di misura	Categoria	Commento
Circular stage 2 - Waste Scenario	0,923	kg	Altri	

Input

Input noti da tecnosfera (materiali/combustibili)

Nome	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max
Jeans - Avoided impact circular stage 2	0,923	kg	Non definito			
(Inserisci linea qui)						

Input noti da tecnosfera (elettricità/calore)

Nome	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)							

Output

I tipi di materiale e/o rifiuto sono separati dallo stream rifiuto

Scenario/processo di smaltimento	Tipo di Materiale / Rifiuto	Percentuale	Commento
PET {waste treatment} {GLO}| recycling of PET | Conseq, U	Textile, woven cotton {GLO}| market for | Conseq, U	30 %	
(Inserisci linea qui)			

Flussi di rifiuto rimasti dopo la separazione

Scenario/processo di smaltimento	Percentuale	Commento
Waste textile, soiled {RoW}| treatment of, municipal incineration | Cons	100 %	
(Inserisci linea qui)		

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File Modifica Calcola Strumenti Finestra Aiuto

Rete | Albero | Valutazione dell'impatto | Inventario | Contributo processo | Impostazione di calcolo | Controlli (1058, 1) | Panoramica del prodotto

Caratterizzazione | Valutazione dei Danni | Normalizzazione | Peso | Punteggio singolo

Ignora categorie: Mai

Standard / Gruppo — Unità predefinite / Escludere il lungo termine / Per ogni categoria d'impatto

Sele	Categoria d'impatto	Unità	Totale	Pair of jeans - Circular stage 2	Transport, freight, light commercial vehicle {Europe without Switzerland}| processing | Conseq, U	Electricity, medium voltage {IT}| electricity voltage transformation from high to medium voltage | Conseq,	Electricity, medium v transformation from
☑	Climate change Human Health	DALY	0,00021	2,05E-5	5,09E-6	8,84E-5	7,7E-5
☑	Ozone depletion	DALY	3E-7	1,48E-7	1,72E-9	1,26E-9	1,1E-9
☑	Human toxicity	DALY	2,99E-5	4,33E-6	1,08E-6	1,13E-5	9,8E-6
☑	Photochemical oxidant formation	DALY	1,58E-8	1,84E-9	9,35E-10	6,12E-9	5,33E-9
☑	Particulate matter formation	DALY	6,89E-5	9,68E-6	2,27E-6	2,62E-5	2,28E-5
☑	Ionising radiation	DALY	1,06E-7	4,77E-8	3,88E-9	9,42E-9	8,21E-9
☑	Climate change Ecosystems	species.yr	1,19E-6	1,16E-7	2,88E-8	5,01E-7	4,36E-7
☑	Terrestrial acidification	species.yr	4,74E-9	5,71E-10	1,06E-10	1,91E-9	1,66E-9
☑	Freshwater eutrophication	species.yr	2,65E-9	3,28E-10	3,77E-11	1,08E-9	9,45E-10
☑	Terrestrial ecotoxicity	species.yr	3,64E-8	1,81E-8	7,2E-11	1,47E-10	1,28E-10
☑	Freshwater ecotoxicity	species.yr	1,57E-9	3,25E-10	4,45E-11	4,84E-10	4,21E-10
☑	Marine ecotoxicity	species.yr	2,92E-10	5,69E-11	8,79E-12	9,3E-11	8,1E-11
☑	Agricultural land occupation	species.yr	2,27E-7	1,03E-7	1,02E-8	1,8E-8	1,57E-8
☑	Urban land occupation	species.yr	3,06E-8	3,53E-9	2,7E-9	1,19E-8	1,04E-8
☑	Natural land transformation	species.yr	2,38E-9	-5,28E-9	2,2E-9	6,25E-9	5,44E-9
☑	Metal depletion	$	0,307	0,0637	0,0503	0,078	0,0679
☑	Fossil depletion	$	5,43	0,565	0,216	2,24	1,95

Analizzando 2 p 'Pair of jeans - Life cycle - Circular stage 2'; Metodo: ReCiPe Endpoint (H) V1.11 / Europe ReCiPe H/A / Caratterizzazione

POLIMI 001 | 8.0.4.30 Analyst | mercoledì 11 marzo 2020

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File Modifica Calcola Strumenti Finestra Aiuto

Rete | Albero | Valutazione dell'impatto | Inventario | Contributo processo | Impostazione di calcolo | Controlli (1058, 1) | Panoramica del prodotto

Caratterizzazione | Valutazione dei Danni | Normalizzazione | Peso | Punteggio singolo

Ignora categorie: Mai

Standard / Gruppo — Unità predefinite / Escludere il lungo termine / Per ogni categoria d'impatto

Sele	Categoria di danno	Unità	Totale	Pair of jeans - Circular stage 2	Transport, freight, light commercial vehicle {Europe without Switzerland}| processing | Conseq, U	Electricity, medium voltage {IT}| electricity voltage transformation from high to medium voltage | Conseq,	Electricity, medium v transformation from
☑	Human Health	DALY	0,000309	3,47E-5	8,44E-6	0,000126	0,00011
☑	Ecosystems	species.yr	1,49E-6	2,37E-7	4,42E-8	5,41E-7	4,71E-7
☑	Resources	$	5,74	0,629	0,266	2,32	2,02

Circular Stage 3 – LCA Design & Findings

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File Modifica Calcola Strumenti Finestra Aiuto

Documentazione | Input/Output | Parametri | Descrizione del sistema

Prodotti

Output noti a tecnosfera. Prodotti e coprodotti

Nome	Quantità fisica	Unità di misura	Quantità fisic	% Allocazion	Tipo rifiuto	Categoria	Commento
Jeans - Avoided impact circular stage 3	0,923	kg	Mass	100 %	non definito	Textiles\Transformation	
(Inserisci linea qui)							

Output noti a tecnosfera. Prodotti evitati

Nome	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Viscose fibre {GLO}| viscose production | Conseq, U	0,1492	kg	Non definito				
Textile, woven cotton {GLO}| production | Conseq, U	0,5871	kg	Non definito				
Polyethylene terephthalate, granulate, amorphous {RoW}| production | Conseq, U	0,12255	kg	Non definito				
Polyurethane, flexible foam {RoW}| production | Conseq, U	0,018	kg	Non definito				
(Inserisci linea qui)							

Input

Input noti da natura (risorse)

Nome	Sottocompartimento	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)								

Input noti da tecnosfera (materiali/combustibili)

Nome	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max
Jeans - Virgin production	0,923	kg	Non definito			
(Inserisci linea qui)						

Input noti da tecnosfera (elettricità/calore)

Nome	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)							

Output

Emissioni nell'aria

Nome	Sottocompartimento	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)								

Emissioni in acqua

Nome	Sottocompartimento	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)								

Emissioni nel terreno

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File Modifica Calcola Strumenti Finestra Aiuto

Input/Output | Parametri

Nome: Pair of jeans - Circular stage 3

Immagine

Commento

Stato: Nessuno

Materiali/assemblaggi	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Jeans - Avoided impact circular stage 3	0,923	kg	Non definito				
(Inserisci linea qui)							

Processi	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Spinning, bast fibre {RoW}| processing | Conseq, U	0,304	kg	Non definito				
Weaving, bast fibre {RoW}| processing | Conseq, U	0,304	kg	Non definito				
Transport, freight train {RoW}| electricity | Conseq, U	6128	kgkm	Non definito				
Transport, freight, light commercial vehicle {Europe without S	101	kgkm	Non definito				
(Inserisci linea qui)							

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File Modifica Calcola Strumenti Finestra Aiuto

Input/Output | Parametri

Nome: Pair of jeans - Life cycle - Circular s

Immagine

Commento

Stato: Nessuno

Assemblaggio	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Pair of jeans - Circular stage 3	1	p	Non definito				

Processi	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Transport, freight, light commercial vehicle {Europe without S	987,61	kgkm	Non definito				
Electricity, medium voltage {IT}| electricity voltage transform	15,3	kWh	Non definito				UK/France average for washing (x6)
Electricity, medium voltage {IT}| electricity voltage transform	24,5	kWh	Non definito				UK/France average for line and drying (x6)
Transport, freight, lorry 7.5-16 metric ton, EURO6 {RoW}| tr	230,75	kgkm	Non definito				
(Inserisci linea qui)							

Scenario smaltimento/fine vita: Circular stage 3 EOL

Commento

Cicli di vita supplementari	Numero	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)						

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File Modifica Calcola Strumenti Finestra Aiuto

Rete | Albero | Valutazione dell'impatto | Inventario | Contributo processo | Impostazione di calcolo | Controlli (1058, 1) | Panoramica del prodotto

Caratterizzazione | Valutazione dei Danni | Normalizzazione | Peso | Punteggio singolo

Ignora categorie: Mai

Standard / Gruppo

Unità predefinite / Escludere il lungo termine / Per ogni categoria d'impatto

Sele	Categoria d'impatto	Unità	Totale	Pair of jeans - Circular stage 3	Transport, freight, light commercial vehicle {Europe without Switzerland}| processing | Conseq, U	Electricity, medium voltage {IT}| electricity voltage transformation from high to medium voltage | Conseq,	Electricity, medium v transformation from
☑	Climate change Human Health	DALY	3,6E-5	2,85E-6	2,54E-6	1,11E-5	1,77E-5
☑	Ozone depletion	DALY	1,99E-8	9,42E-9	8,61E-10	1,57E-10	2,52E-10
☑	Human toxicity	DALY	4,92E-6	5,82E-7	5,41E-7	1,41E-6	2,25E-6
☑	Photochemical oxidant formation	DALY	2,91E-9	2,87E-10	4,67E-10	7,65E-10	1,22E-9
☑	Particulate matter formation	DALY	1,15E-5	1,38E-6	1,13E-6	3,28E-6	5,24E-6
☑	Ionising radiation	DALY	1,38E-8	7,06E-9	1,94E-9	1,18E-9	1,89E-9
☑	Climate change Ecosystems	species.yr	2,04E-7	1,61E-8	1,44E-8	6,26E-8	1E-7
☑	Terrestrial acidification	species.yr	7,82E-10	7,57E-11	5,29E-11	2,39E-10	3,83E-10
☑	Freshwater eutrophication	species.yr	4,26E-10	4,47E-11	1,88E-11	1,36E-10	2,17E-10
☑	Terrestrial ecotoxicity	species.yr	2,42E-9	1,21E-9	3,6E-11	1,84E-11	2,95E-11
☑	Freshwater ecotoxicity	species.yr	2,3E-10	3,14E-11	2,22E-11	6,05E-11	9,68E-11
☑	Marine ecotoxicity	species.yr	4,36E-11	5,73E-12	4,4E-12	1,16E-11	1,86E-11
☑	Agricultural land occupation	species.yr	1,47E-8	7,64E-9	5,11E-9	2,25E-9	3,61E-9
☑	Urban land occupation	species.yr	6E-9	7,54E-10	1,35E-9	1,49E-9	2,39E-9
☑	Natural land transformation	species.yr	2,87E-9	1,03E-10	1,1E-9	7,81E-10	1,25E-9
☑	Metal depletion	$	0,0654	0,0117	0,0252	0,00975	0,0156
☑	Fossil depletion	$	0,948	0,0816	0,108	0,28	0,448

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File Modifica Calcola Strumenti Finestra Aiuto

Rete | Albero | Valutazione dell'impatto | Inventario | Contributo processo | Impostazione di calcolo | Controlli (1058, 1) | Panoramica del prodotto

Caratterizzazione | Valutazione dei Danni | Normalizzazione | Peso | Punteggio singolo

Ignora categorie: Mai

Standard / Gruppo

Unità predefinite / Escludere il lungo termine / Per ogni categoria d'impatto

Sele	Categoria di danno	Unità	Totale	Pair of jeans - Circular stage 3	Transport, freight, light commercial vehicle {Europe without Switzerland}| processing | Conseq, U	Electricity, medium voltage {IT}| electricity voltage transformation from high to medium voltage | Conseq,	Electricity, medium v transformation from
☑	Human Health	DALY	5,25E-5	4,82E-6	4,22E-6	1,57E-5	2,52E-5
☑	Ecosystems	species.yr	2,31E-7	2,6E-8	2,21E-8	6,76E-8	1,08E-7
☑	Resources	$	1,01	0,0933	0,133	0,29	0,464

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