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**Final thesis**

# Life Cycle Assessment in the textile industry

## A useful tool for sustainable fashion?

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# DEDICATORIA

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# List of acronyms

- LCA - Life Cycle Assessment
- SDGs – Sustainable Development Goals
- EP&L – Environmental Profit and Loss account
- CSRD – Corporate Sustainability Reporting Directive
- EFRAG – European Financial Reporting Advisory Group
- TBL/3BL – Tripple Bottom Line
- ESG – Environmental, Social and corporate Governance
- GHG – Greenhouse gas emissions
- IoT – Internet of Things
- OECD – Organization for Economic Cooperation and Development
- IFRS – International Reporting Financial Standards
- LCI – Life Cycle Inventory
- LCIA – Life Cycle Impact Assessment
- SLCA – Social Life Cycle Assessment
- LCC – Life Cycle Costing
- LCSA – Life Cycle Sustainability Assessment
- LCTA – Life Cycle Thinking Assessment
- WLCA – Water Life Cycle Assessment
- ELCA – Energy Life Cycle Assessment
- WLCA – Waste Life Cycle Assessment
- UNEP – United Nations Environment Programme
- f-LCC – Financial Life Cycle Cost
- e-LCC – Environmental Life Cycle Cost
- s-LCC – Societal Life Cycle Cost
- C2G – Cradle-to-Grave
- C2Gt - Cradle-to-Gate
- Gt2Gt – Gate-to-Gate
- Gt2G – Gate-to-Grave
- C2C – Cradle-to-Cradle
- JRC – Joint Research Centre
- PBs – Planetary Boundaries
- CE – Circular Economy
- PET – Polyethylene-terephthalate
- PES – Polyester
- TfS – Traceability for Sustainability
- DJSI – Dow Jones Sustainability Index
- IO – Input-Output

# Abstract

The fashion industry is generally known by two variants: one that gives a glimpse of the luxury and comforts that it can create, and another that combines countless environmental, social, and economic impacts that are caused by its different economic models, among which fast fashion stands out.

The general aim of this thesis, through a bibliographic analysis and synthesis as well as a case study on the Kering group, is to prove how implementing Life Cycle Assessment (LCA) along with other decision-making tools can bring great benefits. This means showing and proving, with true data, that increasing sustainability in the fashion industry is not only possible but also profitable in the long term if the right data is properly and consistently analyzed through tools of scientific reason such as LCA. In this way, the same industry that was once labeled as the second most polluting in the world can distance itself from that bad reputation and make a fair transition based on knowledge, criteria, and scientific studies.

The synthesis of the literature is based on a general analysis of the bibliography that was available up until the date of the thesis presentation, focusing primarily on documents relevant within the geographical framework of the European Union. Additionally, external studies and factors are considered since, by the very nature of the fashion industry, it is necessary to expand the horizons of both the impacts and the studies conducted as a result of these impacts. At the same time, the thesis prioritizes and highlights sections to take into account, such as the following: the complex relationship between the fashion industry and sustainability, the importance of harmonizing and properly controlling the supply chain, the assignment of tiers to each of the intermediaries within the supply chain, the connection between life cycle assessment and the Sustainable Development Goals (objectives that have been marked as priorities), the imminent need to redesign the products of the present and the future under eco-design criteria to facilitate their recycling (evolving from the concept of waste to a new raw material), and the importance of the consumer as a decisive agent within the life cycle of a product. Additionally, this thesis includes the results from a focused literature review of 8 articles on LCA in fashion supply chains are presented. Finally, it is important to mention that this document has been written with the purpose of laying the foundations so that managers and directors can take advantage of this method as a decision-making tool and thus help to develop strategies in accordance with the criteria of sustainability and a circular economy. Therefore, it was a priority to develop a case study on the application of LCA in a real fashion company. The multinational group Kering, that applies LCA under the Environmental Profit and Loss (EP&L) account methodology, supports this premise.

KEYWORDS

Life Cycle Assessment (LCA), Sustainability, Environmental Impacts, Textile Industry, Fashion, Tier, Supply Chain, Boundary system, Circular economy, Sustainable Development Goals (SDGs), Recycling, Consumer use, Environmental Profit and Loss (EP&L) account, Kering.

## Resumen

La industria de la moda se conoce generalmente por dos variantes: aquella que ofrece un vistazo del lujo y las comodidades que puede crear, o los innumerables impactos ambientales, sociales y económicos que son causados por sus diferentes modelos económicos, entre los que destaca el fast fashion.

El objetivo general de esta tesis, a través de un análisis y síntesis bibliográfica y de un caso de estudio sobre el grupo Kering, es demostrar cómo la implementación del Análisis de Ciclo de Vida (ACV) junto con otras herramientas de toma de decisiones puede aportar grandes beneficios. Esto significa demostrar y probar, con datos reales, que aumentar la sostenibilidad en la industria de la moda no solo es posible, sino también rentable a largo plazo si se analizan de manera adecuada y consistente los datos correctos a través de herramientas de razón científica como el ACV. De esta manera, la misma industria que una vez fue etiquetada como la segunda más contaminante del mundo puede distanciarse de esa mala reputación y hacer una transición justa basada en el conocimiento, los criterios y los estudios científicos.

La síntesis de la literatura parte de un análisis general de la bibliografía disponible en la fecha en que se presenta la tesis, también centrándose en documentos principalmente relevantes dentro del marco geográfico de la Unión Europea. Además, se consideran estudios externos y factores adicionales, ya que, por la propia naturaleza de la industria de la moda, es necesario ampliar los horizontes tanto de los impactos como de los estudios realizados como resultado de estos impactos. Por otro lado, la tesis prioriza y destaca secciones a tener en cuenta, como la compleja relación entre la industria de la moda y la sostenibilidad, la importancia de armonizar y controlar adecuadamente la cadena de suministro, la asignación de niveles tier a cada uno de los intermediarios dentro de la cadena de suministro, la conexión entre el análisis de ciclo de vida y los Objetivos de Desarrollo Sostenible (objetivos que se han marcado como prioritarios), la necesidad inminente de rediseñar los productos del presente y del futuro bajo criterios de ecodiseño para facilitar su reciclaje (evolucionando desde el concepto de residuos hacia una nueva materia prima) y la importancia del consumidor como agente decisivo dentro del ciclo de vida de un producto. Así mismo, se presentan los resultados de una revisión bibliográfica enfocada en 8 artículos sobre ACV en las cadenas de suministro de moda. Finalmente, es importante mencionar que este documento ha sido escrito con el propósito de sentar las bases para que los gestores, directores y responsables de las empresas puedan aprovechar esta metodología como una herramienta de toma de decisiones y, por lo tanto, ayudar a desarrollar estrategias de acuerdo con los criterios de sostenibilidad y economía circular. Por lo tanto, fue una prioridad desarrollar un caso de estudio sobre la aplicación del ACV en una empresa de moda real. El grupo multinacional Kering, que aplica el ACV bajo la metodología de Cuenta de Pérdidas y Ganancias Ambientales (EP&L), respalda esta premisa.



Palabras clave

Análisis de ciclo de vida (ACV), Sostenibilidad, Impactos medioambientales, Industria Textil, Moda, Tier, Cadena de suministro, Sistema de límites, Economía circular, Objetivos de Desarrollo Sostenible (ODS), reciclaje, Uso del consumidor, Cuenta de pérdidas y ganancias ambientales (P&GA), Kering.


## 1. Introduction

When discussing the fashion industry, it is important to acknowledge that, like all other industries, it is entirely reliant on a variety of factors, including two key ones: people, who both consume and produce, and resources, which serve as the raw materials for everything we consume. Resources are granted by the planet we live in, for which we are all, to varying degrees, responsible.

After generations of thoughtless production and consumption within a linear system, the world is now facing a turning point where current and future generations must develop new strategies to rebuild the fashion industry and evolve towards a new era of sustainability. According to The State of fashion 2023, "*Fashion is among the most unsustainable industries on the planet, responsible for around 3 percent to 5 percent of global carbon emissions*" (Business of Fashion & McKinsey & Company, 2022, p. 42). Therefore, it is crucial for the fashion industry to shift its trajectory and embrace the new possibilities of **innovation** (technological, scientific, and social) that have emerged, such as **Life Cycle Assessment[1].** This tool can aid in the redesign of supply chains, transforming the industry into one that is more efficient, ethical, and has a lower environmental impact, with a restorative character for the world in which we live.

The European Commission is promoting new legislative regulations such as the **Corporate Sustainability Reporting Directive** (CSRD) where textiles are one of the top 5 priority industries to receive specific standards and requirements for the sector. The CSRD, along with another regulation proposal called **The EU Strategy for Sustainable and Circular Textiles**, both comply with **The European Green Deal** (European Commission, 2019; Directive (EU) 2022/2464 of the European Parliament and of the Council, 2022). The ultimate goal is to turn Europe into the world leader in terms of shifting the current world economic model towards a **greener** and **circular economy[2]**.

Given these regulations, it is clear that the fashion industry will undergo a series of structural changes. While this will undoubtedly be challenging, it is also an **opportunity** to begin incorporating best practices, developing a **new resilience** through a deeper understanding of the industry's supply chain and its effects (both positive and negative), and addressing factors that represent a risk to the industry's path towards **sustainability[3]**.

The **Life cycle assessment (LCA)** is a fully developed tool that was "invented" up to more than 60 years ago: "*The first studies that are now recognized as (partial) LCAs date from the late 1960s and early 1970s*"(Guinée et al., 2011, p. 1). LCA has all the possibilities to become one of the main sources of information not only for the **mitigation[4]** of **climate change**, but also for tackling other problems primarily associated with the environment. Additionally, LCA is an extremely useful tool, as it takes into account the impact that both **society** and the **economy** have on sustainability**.**

This tool in the words of Hauschild et al "*analyses the whole lifecycle of the system or product that is the object of the study and it covers a broad range of impacts for which it attempts to perform a quantitative assessment*" (Hauschild et al., 2018, p. 5). This means that it focuses on analyzing the various phases of a product's life, as well as its processes and services. By doing

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[1] "Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle"(International Organization for Standardization, 2006a, p. 8).

[2] "An economic system whereby the value of products, materials and other resources in the economy is maintained for as long as possible, enhancing their efficient use in production and consumption, thereby reducing the environmental impact of their use, minimising waste and the release of hazardous substances at all stages of their life cycle, including through the application of the waste hierarchy" (EFRAG, 2022, p. 11).

[3] "Meets the needs of the present without compromising the ability of future generations to meet their own needs"(United Nations, 1987, p. 37).

[4] " Refers to the introduction of measures to avoid, reduce and/or compensate for any significant adverse impact"(Muthu & Textile Institute, 2015, p. 153).

so, we can determine the possible impacts and potential consequences from a scientific perspective, providing mainly quantifiable data, while also considering qualitative data, which can have a substantial impact on the quantification of results. The key aspect of LCA analysis is the need to rely, always, on **something that is comparable**.

The **general objective** of this document consists of supporting the argument that the Life Cycle Assessment (LCA) is and will continue to be one of the most important tools for the textile industry, especially for fast fashion companies who want to move towards sustainability.

At the same time, the aim of the analysis is to quantify and qualify the progress of the LCA within the fashion industry and to assess to which extent this tool has laid the foundations for legitimate sustainability. It also seeks to clarify and respond to the following points:

- Explain sustainability in the textile industry and how it can be achieved.
- Is it possible for a fast fashion company to be sustainable?
- Define the concept and the tool of LCA.
- Why should this tool be used throughout the supply chain?
- Analyze the benefits and contributions to the textile industry by the LCA.

The **methodology** consists of combining a bibliographic synthesis of documentation between the years 2012 - 2023 with a case study. Although it would be ideal to limit this bibliographic analysis to a specific region and time, the limited amount of information and work in the textile industry necessitates the use of the most recent studies and books that may be useful for this research. Since the fashion industry is one of the most **offshored** and **global** industries, the initial delimitation will be "**Europe**," although studies, regardless of their country of origin, will also be included as long as they provide information that represents progress and benefit for the fashion industry.

This document also aims to assist practitioners within the fashion industry, particularly those whose knowledge is **not linked to chemistry or engineering**. The purpose of this work is simply to lay the foundations and explain from the perspective of **business management** why the Life Cycle Assessment (LCA) is something that companies should consider when developing their economic activities in an efficient and sustainable way. Depending on the size of the business, companies can implement the LCA to a greater or lesser extent, bringing the fashion business closer to a new level of sustainability.

# 2. Context and conceptual framework

Before delving into the main topic of this thesis, it is important to briefly discuss some documents and definitions that have shed light on the urgency to develop and implement tools like LCA. These tools are necessary to address the current linear model of production and consumption, as this model has led to serious problems of production, consumption, waste, and violation of rights at a general level.

1) The tragedy of the commons: in 1968, Garret Hardin's article "The Tragedy of the Commons" described a problem he called the "backwards tragedy," in which society observes not only the depletion of resources, but also the addition of a negative substance in the form of pollution (Hardin, 1968). Elinor Ostrom's response to Hardin in "Governing the Commons" built upon both Hardin's theory and the concept of the prisoner's dilemma, arguing that this tragedy can be avoided through **collaboration and contextual understanding**. She backed up her opinion with empirical evidence that she gathered and analyzed (Ostrom, 1990).

2) The Brundtland Report, "Our Common Future": this 1987 document not only provides the most frequently cited definition of **sustainable development**, but also it emphasizes the significance of **collective action** and **multilateralism** in shaping the shared future of humanity. The report urges us to prioritize action using the available tools to **restore** what has been damaged by our harmful way of life. Our dependence on the environment holds us responsible for past, present, and future actions (Commission on Environment, 1987).
3) **Triple Bottom Line**[5] (TBL/3BL): the book "Cannibals with forks: Triple Bottom Line of 21st Century Business" from John Elkington published in 1997 was one of the first publications, if not the first one, to talk about the Triple Bottom Line approach. Starting from the metaphor of the "**bottom line**" also called net income, net profit, or net loss, Elkington's work laid the foundation for the current **ESG**[6] criteria. In addition to this, he presents several examples and points that highlight the direct and **interdependent** relationship in terms of how an economic activity is developed, considering the **three fundamental pillars for sustainability**: environment, society, and economy, also known as people, profit and planet (Elkington, 1997).
4) **Sustainable Development Goals (SDG)**: the 2030 agenda passed in 2015, with 17 goals and 169 targets, is currently one of the biggest drivers and best descriptions of the path that the world and therefore the fashion industry must follow in order to achieve sustainability. Later in this thesis, this topic will be discussed again, where the importance of this agenda and its relationship with the fashion industry will be analyzed in more depth (UN General Assembly, 2015).
5) **The Paris Agreement:** is one of the most widely referenced and discussed agreements of recent times. This 2015 agreement brings together over 169 countries with the aim of reducing global temperatures and mitigating **greenhouse gas (GHG)**[7] **emissions**, ultimately achieving **climate neutrality** by the mid-century. The document emphasizes the significance of **shared responsibility** but acknowledges the limits of each party's capacity and actual responsibilities (United Nations, 2015).
6) **Corporate Sustainability Reporting Directive (CSRD)**: this new regulation, implemented by the European Union since January 5, 2023, is probably one of the most comprehensive documents to demand **accountability** from companies. This directive is a vital part of achieving the objectives set out in the 2030 agenda, the Paris Agreement, the European Green Deal, and many others by 2050. One significant stipulation is that all companies, regardless of size, must participate explicitly in explaining, in a transparent and standardized way, how they are working and what their negative and positive contributions are regarding different **material factors** associated with **ESG criteria**. The LCA, in combination with the **Double Materiality Analysis**[8] (the basis of this directive), can lay the foundations for future companies, particularly in the textile industry, given its high level of complexity in terms of

[5] "Sustainable development involves the simultaneous pursuit of economic prosperity, environmental quality, and social equity. Companies aiming for sustainability need to perform not against a single, financial bottom line but against the triple bottom line"(Elkington, 1997, p. 397).

[6] Acronym of: Environmental, Social and Governance.

[7] "Greenhouse Gases (GHG) are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself and by clouds. This property causes the greenhouse effect. Water vapour (H2O), carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4) and ozone (O3) are the primary GHGs in the Earth's atmosphere. Moreover, there are a number of entirely human-made GHGs in the atmosphere, such as the halocarbons and other chlorine-and bromine-containing substances, dealt with under the Montreal Protocol. BesidesCO2, N2O and CH4, the Kyoto Protocol deals with the GHGs sulphur hexafluoride (SF6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs)"(EFRAG, 2022, p. 16).

[8] "Double materiality has two dimensions: impact materiality and financial materiality. A sustainability matter meets the criterion of double materiality if it is material from the impact perspective or the financial perspective or both."(EFRAG, 2022, p. 13).

its supply chain and exponential and multilateral scope. The importance of implementing and combining several tools to reach the most effective and efficient results will be discussed later (Directive (EU) 2022/2464 of the European Parliament and of the Council, 2022).

This does not mean that other milestones in the history of sustainability are not worth discussing. In fact, there are so many that investigating them all would require doing several papers. However, the concepts and documents highlighted here are the main milestones that have influenced different professionals in their search to create methodologies, techniques, and tools to help change the world regarding creation and consumption. Subsequently, they have also inspired and shaped this thesis.

## *2.1 The fashion industry and the sustainability dilemma*

The fashion industry can be considered a relatively young industry. We only need to think about how long ago the first sewing machine was created: the mid-1700s. Although it is true that the invention has been attributed to many people, the majority of these only patented improvements of the original model created by Charles Fredrick Wiesenthal in 1755 (BrandStocker, 2019).

At that moment in history, the fashion industry experienced one of its first great evolutions. It was directly boosted after the **first industrial revolution** in 1760, when the transition from sewing by hand to using a tool greatly reduced the time and effort needed to produce clothes. This innovation translated into better performance and a new level of efficiency, giving garments a new quality. Decades later, after the **second industrial revolution** in 1870, new innovations enabled the exponential growth of previous advances. This amplified the amount of material and labor necessary to meet the new needs of an increasingly growing and demanding population. Closer to modern times, the **third industrial revolution** began, which changed the fashion industry forever. This was due to the beginning of automation across industries, but also the rise of the **fast fashion**[9] **business model**. Finally, we are currently living in the **fourth industrial revolution**, where the **Internet of things (IoT)** and the awakening of the massive online sales represent a new era inside the industry (industry 4.0). At the same time, this poses a huge risk when talking about sustainability issues in the fashion industry and their supply chains (IBERDROLA, n.d.).

In the late 19th century, fashion democratization began and was fully established in the 20th century. Meanwhile, **offshoring** was developed as a measure to increase profit margins and reduce costs, particularly in the manufacturing stage. This led to a redirection of production to "domestic" factories with a high labor intensity, poor infrastructure and machinery quality, and minimal labor specialization (initially). Generally, these are located in vulnerable regions due to their characteristics: these regions provide cheap labor, and working hours can be adjusted to suit the companies that run these workshops, also known as sweatshops (Varley et al., 2019). Moreover, in comparison to developed nations, the laws and regulations in these areas are very lenient, facilitating the normalization of such practices among many companies in these countries. Consequently, they seriously infringe on **human rights**, **workers' rights** and unfortunately **children's rights**, as well.

The implementation of fast fashion during globalization became a mass phenomenon due to the efficient logistics and flexible distribution channels. As a result, many groups and companies in

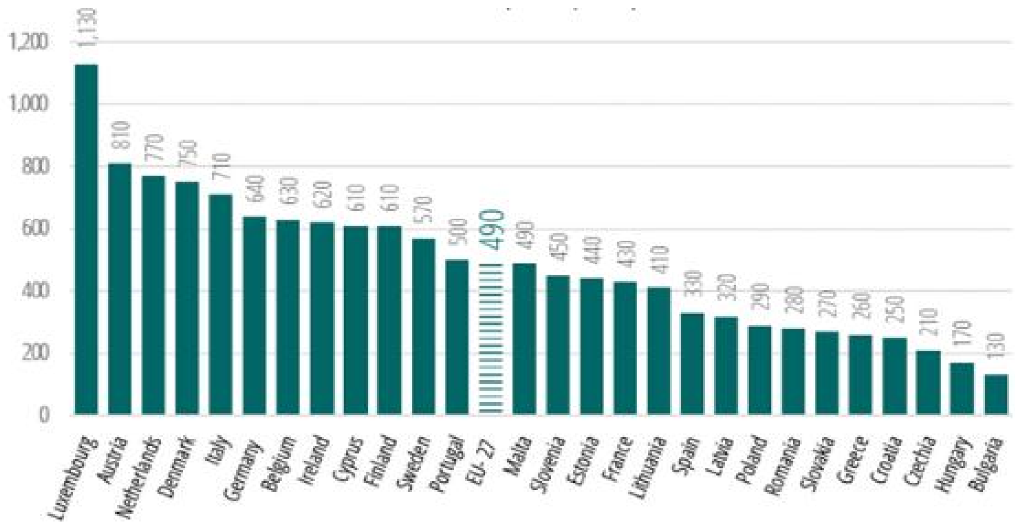
[9] Economic model that seeks a fast production of garments and accessories in very tight times and with low prices, among its characteristics include the offshoring of its production and outsourcing (subcontracting). Example: H&M, UNIQLO... among others.

the textile industry adopted this business strategy, replacing previously established brands that had a reputation and tradition based on craftsmanship and local approaches. **Relocation**, as a key driver in terms of competitiveness (competitive advantage) between companies, played a significant role in this shift in organizational dynamics where profit margins took priority. This transformation greatly impacted the behavior and consumption habits of individuals, who have grown up in a fully globalized world with the availability of products at low prices and, sometimes, also dubious quality. However, the negative effects of such production, consumption, and inappropriate resource and waste management, along with frequent violations of human and labor rights, are slowly coming to light (Varley et al., 2019).

The simple fact that it is an industry based on the overconsumption and overproduction of products with delocalized labor-intensive operations in disadvantaged regions such as Asia, Africa, and Latin America, demonstrates its contribution to social and economic inequalities. These supply chains are **highly intensive** in terms of natural resources consumption such as **water**, **land,** and **mining**, as well as other resources such as **energy** (renewable and based on fossil fuels). This represents a huge environmental and social risk (Varley et al., 2019). All these factors will undoubtedly affect all **ecosystems** and therefore their **biodiversity** (both marine and terrestrial), leaving behind an **enormous environmental footprint**. To make matters worse, there is a **low level of transparency and traceability** within the sector, which makes it exceedingly difficult to correctly describe the scope and consequences of these practices.

Despite the difficulties of accountability, if we analyze **consumption trends** within the European Union, we find alarming data. According to a study of the European Union, "*The EU produces 5kg of textile waste per capita. The largest European markets are also the main producers of waste (e.g., Germany, France, Romania, Poland, and Italy). Although some of these states reduced their waste levels from 2004 onwards, textile waste in the EU27 still amounts to 2.3 billion tonnes, 5% more than in 2004* "(European Commission & Centre for Industrial Studies, 2021, p. 11). An example of these domestic consumption habits by country can be seen in the image below (Figure 1), where the average consumption per household during the year 2020 was 490€, representing a total of more than 200 billion euros of consumption in textile and clothing products (EURATEX, 2022).

*Figure 1. EU household consumption of clothing in 2020 (EUR at 2020 prices, per capita)*




Source: EURATEX-Facts and figures 2022, p.15 (2022).

## *2.2 Supply Chains in the textile industry*

It can be agreed upon both by all literature sources and most textile workers that the **supply chain**[10] within the industry is extremely complex. As pointed out by Riemens et al., "*Fashion is a symptomatic cross-sector based upon global, **fragmented and extremely complex value chains***" (UNECE-UN/CEFACT, 2020, apud Riemens et al., 2022, p. 1). This industry has the potential to increase the economic (and even the social) development of those locations where the most labor-intensive and extractive activities (use of resources) are conducted. However, the whole system is so deeply fragmented that the continuous violations of workers' rights and the careless treatment of the environment may go somewhat unnoticed as we approach **downstream**[11]. This is especially the case if we consider the enormous dispersion between countries as a result of offshoring, which shapes the main structure of current supply chains (OECD, 2018).

To properly understand the complexity of the supply chain of the fashion industry, it is best to use graphic representations, simplifying to some extent the intricate relationship that exists between different producers, suppliers, and retailers, among others. For this purpose, a "basic" garment (**a white t-shirt**) will be taken as a reference. To provide the best possible understanding of this thesis, we will always work with this same example when it comes to introducing unfamiliar terms and characteristics relevant to sustainability and the industry.

In the image below (Figure 2) we can see a simplified version of the supply chain of a 100% white cotton t-shirt of **Company X**. Also, within this graph we must mention that:

1) It is assumed that those who harvest and sow the cotton will be the same ones who will clean, gin and sort it. We will call this business **S-a** (supplier a).

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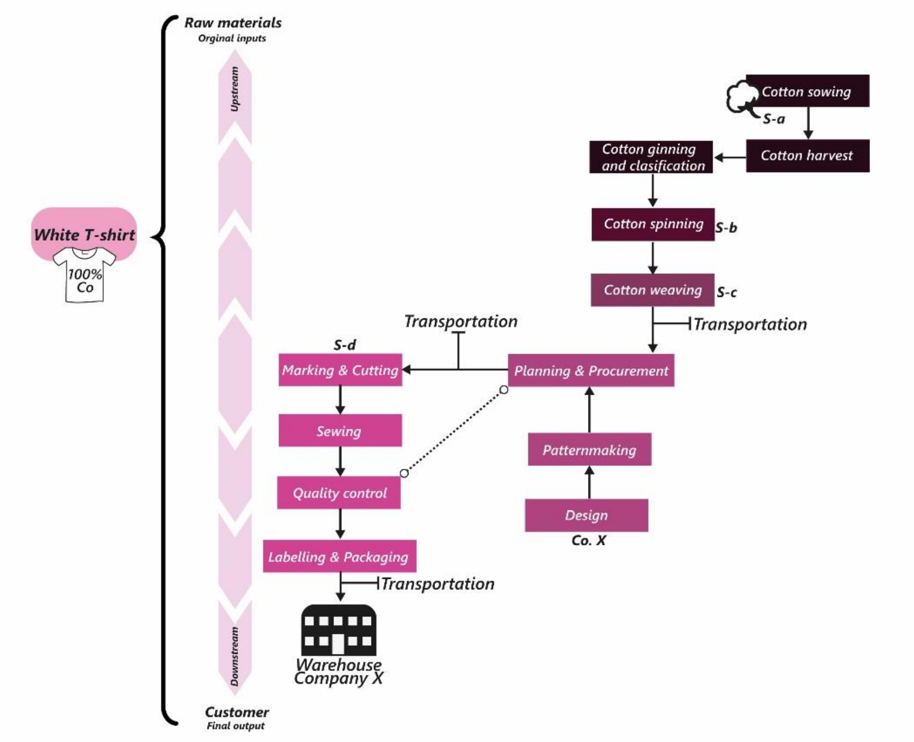
[10] "The full range of activities or processes carried out by entities upstream from the undertaking, which provide products or services that are used in the development of the undertaking's own products or services. This includes upstream entities with which the undertaking has a direct relationship (often referred to as a first-tier supplier) or an indirect business relationship"(EFRAG, 2022, p. 28).

[11] "The entity is considered downstream from the undertaking (e.g., distributors, customers) when it receives products or services from the undertaking" (EFRAG, 2022, p. 7).

2) **S-a** will be the raw material supplier for **S-b** (supplier b) which will manufacture the yarns and threads (spinning process).
3) **S-b** will be the supplier of yarns and threads for **S-c** (supplier c) which will manufacture the fabric, also taking care of the bleaching processes and other treatments necessary for the fabric to reach the desired quality and characteristics.
4) **Company X** has a design department which will handle the shirt design, then transfer the design to the patternmaking area. Once the expected result is obtained, it will be passed to the planning and procurement department to order the amount of fabric and thread necessary for production.
5) **Company X** subcontracts a business—we are going to call it **S-d** (supplier d)—for the production part. Therefore, once the material is received and inspected by **company X**, it is sent to business **S-d**.
6) The business called **S-d** begins to work with the information received from **Company X**, carrying out the entire process of fabricating beds, marking, cutting, and sewing the final garment.
7) Let us assume that **Company X** sends a product manager to the facilities of the business **S-d** to do the quality control of the garments.
8) If everything is okay, business **S-d** proceeds with the labeling and packaging of the garments, which will then be packaged in boxes for transportation to the Company X's warehouse.
9) Finally, the shipment will be received from **business S-d** at the warehouse of **Company X**, where the garments will be counted. Next, the logistic procedures begin to rearrange the shipments in the different **distribution centers** of **Company X**, after which they will eventually be referred to the **stores** until the t-shirts reach the **final consumer**.

*Figure 2. Company X supply chain for a cotton t-shirt*




Source: own creation (2023)

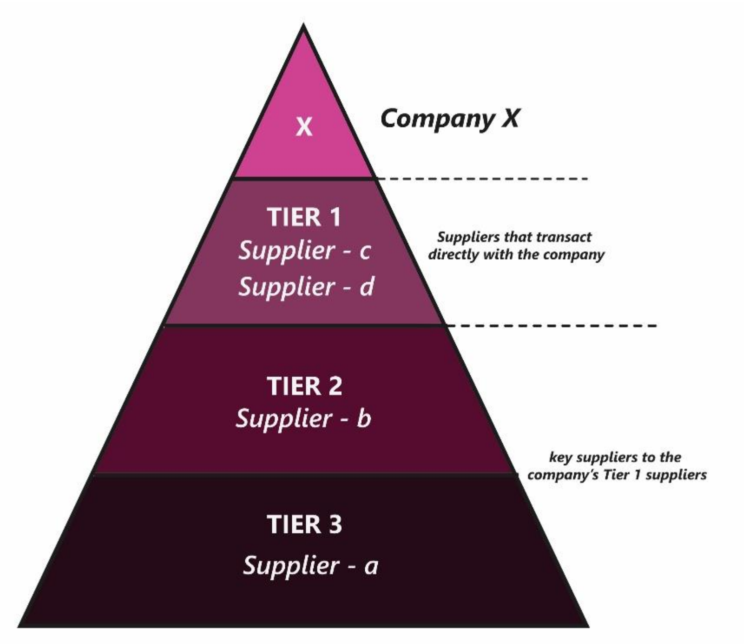
Although the design presents some complexity, it is evident that a lot of information is missing, such as: a more specific breakdown of each party involved; the intermediaries and facilitators involvement; suppliers other than raw materials suppliers (water, energy, chemicals, seeds... etc.), the sub-suppliers or suppliers of our suppliers (chemicals, seeds, machinery, packaging, labels... etc.); and a better and accurate transport intersection, substantially larger than the reflected in the previous figure (figure 2).

In the words of Matt Ripley, "*The process of transforming raw materials into a finished retail product involves many steps, specialisations and spans a number of countries. When a company's supply chain has thousands of suppliers, it represents a major challenge to ensure sustainable practices throughout the chain – particularly in terms of ensuring decent working conditions of freedom, equity, security and human dignity*" (Ripley, 2020, p. 2). So, it is natural that one question arises in our heads. If this supply chain is so unfathomably complicated, how is it possible to change this dynamic and evolve into a new business model that is more sustainable and transparent? Here we find a "novel" term, but one that is an essential asset to unravel the complexity of the supply chain: the term **tier** and its system.

The definition of ***tier*** according to the Cambridge Business English Dictionary is "*one of the levels of management in an organization*"(Cambridge Business English Dictionary, 2023). Likewise, if we focus on the supply chains of the fashion industry, thanks to the **Apparel, Accessories & Footwear Sustainability Accounting Standard**, we have a more exact definition of what a tier is and which are their respective levels. The "methodology" used to assign each supplier a particular level is also clarified. "*Tier 1 suppliers are defined as suppliers that transact directly with the entity, such as finished goods manufacturers (e.g., cut and sew facilities). Suppliers beyond Tier 1 are the key suppliers to the entity's Tier 1 suppliers and can include manufacturers, processing plants, and providers of raw materials extraction (e.g., mills, dye* *houses and washing facilities, sundry manufacturers, tanneries, embroiderers, screen printers, farms, and/or slaughter houses) The entity shall disclose whether any supplier data beyond Tier 1 is based on assumptions, estimates, or otherwise includes any uncertainty*"(IFRS Foundation, 2022, p. 7).

Following the example of the cotton t-shirt made by Company X, we can see below a pyramidal graph (Figure 3) displaying in which tier level each of the suppliers (S-a to S-d) are located[12].

*Figure 3. Company X tier system for a cotton t-shirt.*

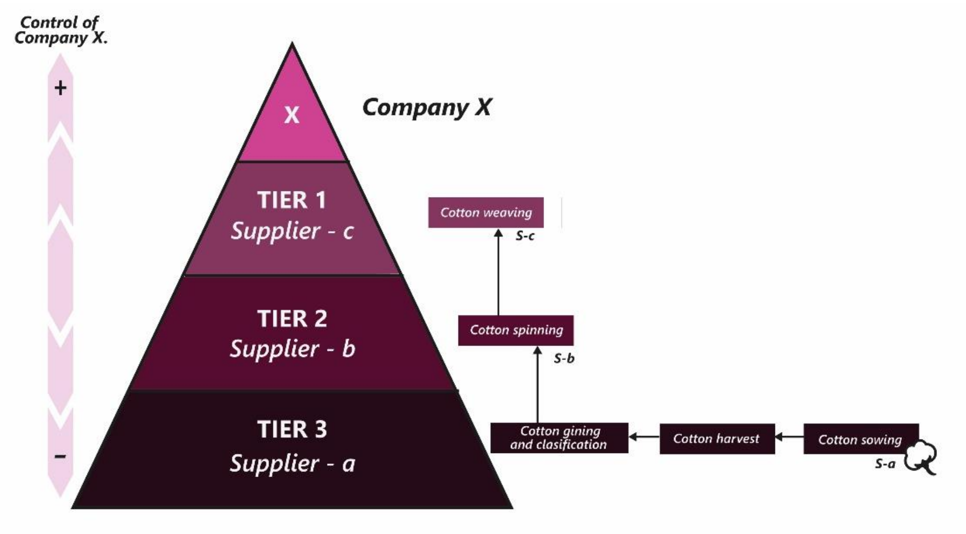



Source: own creation (2023)

As can be observed, along with the added complexity of each new supplier to the chain, their tiers expand. In parallel, the control of Company X over them begins to shrink as reflected in the next image (Figure 4).

[12] There is no clear guideline as to how to categorize tiers currently, one method could be by transformation steps, which means, if each new one implies a transformation of the incoming inputs in said chain link producing a new input for the creation of the final output or in other words, transforming the main material into the final product.

*Figure 4. Company X tier system up to tier 3 for a cotton t-shirt.*




Source: own creation (2023).

Therefore, it is of utmost importance for the fashion industry to clarify or make their tier system more transparent, which brings some order to the complex network of interconnected companies. Moreover, due to the recent increase in regulations affecting all industries conducting economic activity within the European Union, transparent communication regarding company systems has essentially become mandatory for those who wish to continue operating in the EU. Among these regulations, one stands out as having the most significant structural and logistical impact on the fashion industry: Directive (EU) 2022/2464 of the European Parliament and Council, also known as the Corporate Sustainability Reporting Directive (CSRD). This directive not only calls for increased **accountability by companies**, but also requires them to provide specific, quantifiable, and **auditable information** and data to prove their **progress and improvements**. This can only be achieved if companies increase awareness and monitor information regarding their suppliers **beyond tier 1** (Directive (EU) 2022/2464 of the European Parliament and of the Council, 2022; Ripley, 2020).

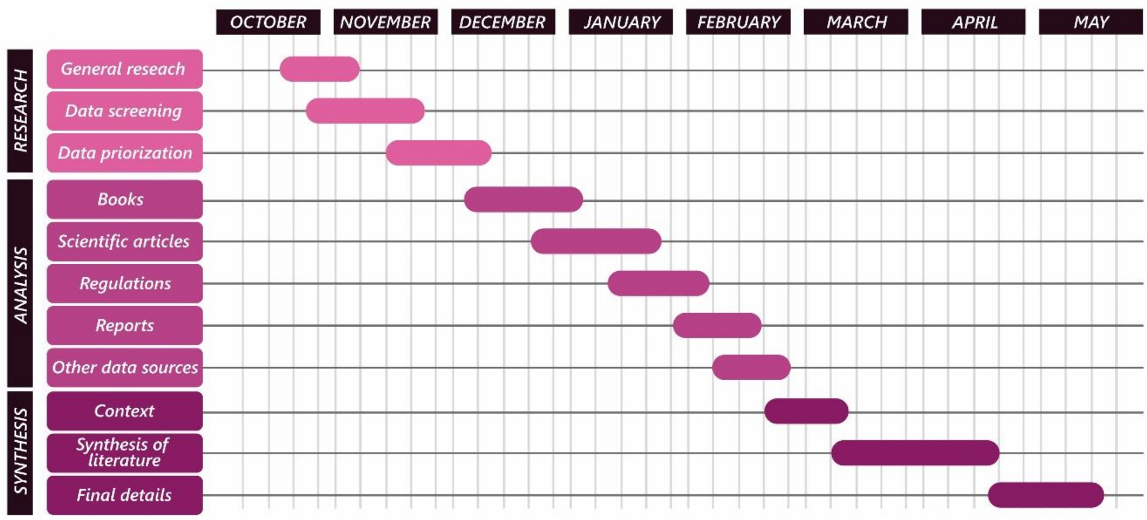
# 3. Methodology

The research conducted to realize this thesis will be divided into 5 stages:

1) Selection and review of diverse sources of information (mainly secondary).
2) The secondary sources will be analyzed in two subphases: first, analysis of books, scientific articles of the journal "The international Journal of Life Cycle Assessment" and regulations linked to the study such as ISO standards of the 14000 family "environmental management" especially the ones about Life Cycle Assessment (UNE-EN ISO 14040:2006, UNE-EN ISO 14040:2006/A1:2021, UNE-EN ISO 14044:2006, UNE-EN ISO 14044:2006/A1:2018, UNE-EN ISO 14044:2006/A2:2021). Secondly, information concerning the case study of the Kering group, whose data have been collected primarily by reports and documents of a public nature.
3) Analysis of other secondary sources, which are mainly publishers of the fashion industry with a more entrepreneurial perspective (grey literature).
4) A final search to ensure there are no information gaps within the analysis and that the key points of the study are covered in a clear and concise manner.

5) Synthesis of the collected information, thus developing a bibliographic analysis. A meticulous selection of 8 articles has been made to cover different phases and materials within the fashion industry, aiming to reflect the current reality and demonstrate how it can benefit from using tools such as LCA. Each of these articles will have its own section where their key characteristics and related results will be explained. The detailed structure of the thesis will be extensively discussed in the table of contents section.

*Graphic 1. Thesis timetable.*




Source: own creation (2023).

# 4. Life Cycle Assessment (LCA) and sustainability

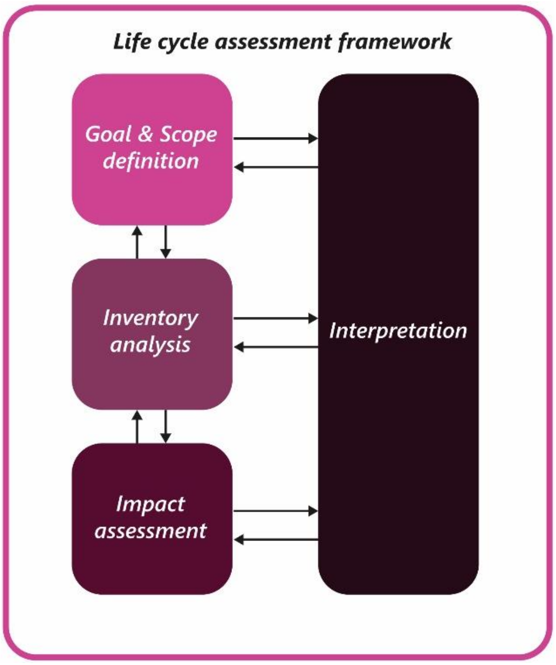
## *4.1 Life Cycle Assessment as a family of tools*

So far it has been mentioned several times how the industry needs a change. It becomes more than evident if we analyze the current **EU strategy on circular and sustainable textiles:** "*These challenges and opportunities call for more systemic solutions in line with the European Green Deal ambition to make growth sustainable, climate-neutral, energy-and resource-efficient and respectful of nature, and built around a clean and circular economy. The 2020 Circular Economy Action Plan and the 2021 update of the EU Industrial Strategy identify textiles as a key product value chain with an urgent need and a strong potential for the transition to sustainable and circular production, consumption and business models*"(European Commission, 2022, p. 2). However, these changes cannot be made overnight. I**f there is no data supporting that restructuring, the process cannot be successful** and changes in the business models, strategies, and processes which companies currently follow cannot be sustained. This is where LCA becomes relevant.

The LCA itself is a group of different methodologies and approaches that look to address a general environmental impact of production, but it also addresses social and economic issues. According to **ISO standards** the LCA is a "*compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle*" (International Organization for Standardization, 2006a, p. 8). All this, through data collected during a specific period, under specific delimitations and with previously established metrics, following a rigorous list of requirements[13] and scientifically based criteria. The Life Cycle Assessment (LCA) is a **powerful tool** that offers many benefits. It **goes beyond** merely collecting data on each **impact category** and can be used for various purposes, including **risk and opportunity analysis** by management teams and policymakers. In fact, the LCA has the potential to become a **strategic tool**, aiding different sectors in their transition towards sustainability by promoting good practices and collaborating with other methodologies (Hauschild et al., 2018; Muthu & Textile Institute, 2015).

The **ISO 14040:2006 Standard** specifies which phases of an LCA study must be followed as shown in the next image (Figure 5)(International Organization for Standardization, 2006a).

*Figure 5. LCA framework.*




Source: adapted from ISO 14040:2006 Standard, 2006, p.18 (2006).

**Goal & Scope definition**: as its name shows, it is a question of setting up which limits exist for conducting the study throughout the life cycle[14] of a product (the scope). In this section it will be clarified what is the main aim of the study (the goal), usually associated with questions or concerns about a product or process related to the supply chain and/or life cycle (Hauschild et al., 2018; Muthu & Textile Institute, 2015).

[13] Data quality requirements are set out in standard UNE- ISO 14044:2006 in the paragraph 4.2.3.6.2 inside the "Data quality requirements" in section 4.2.3.6.(International Organization for Standardization, 2006b)

[14] "Consecutive and interlinked stages, from raw material acquisition or generation from natural resources to final disposal" (International Organization for Standardization, 2006a, p. 8)

**Inventory analysis**: this part is also called **Life Cycle Inventory (LCI)**. It handles collecting the different flows[15] used and created through a product system[16]. It takes into account a wide number of categories of inputs (resources, materials...), as well as outputs (waste, emissions, losses...) needed to create the main product/service, which is usually directly associated with the functional unit[17] and its characteristics and services (Hauschild et al., 2018; Muthu & Textile Institute, 2015).

**Impact Assessment**: this third part is known as **Life Cycle Impact Assessment (LCIA)**. It is essentially about assigning scores (quantitative criteria) to previously collected data (LCI phase). Although this section is mainly implemented by the chosen software (e.g., OpenLCA or SimaPro), it is imperative that the people in charge of this step choose appropriate methods, the impact categories[18] (e.g., climate change), and other relevant factors in the study. As a result, the data found makes it possible to compare and evaluate based on these measurements and estimates, showing the contributions and the magnitude of the environmental impact of each previously studied flow, along with the different chosen impact categories (Hauschild et al., 2018; Muthu & Textile Institute, 2015).

**Interpretation:** this last phase is about interpreting the two previous phases (LCI, LCIA) in a consistent way and always taking into account the first phase (Goal and scope), seeking to provide interpretations and to make reasonable conclusions, always highlighting the limitations of the study and the new recommendations and hypotheses that arise from them (Hauschild et al., 2018; Muthu & Textile Institute, 2015).

The previous framework is a priority and mandatory (following the ISO 14040, ISO 14044 standards) for a suitable development of an LCA. Therefore, it establishes certain basic points for the study. The following sections will orbit around and depend substantially on this selection, as well as the results may present variations depending on the certain cut-off criteria's[19] used when selecting these points:

a) **Functional unit**: this is the qualitative measure that we will convert into a quantitative level in order to make a proper comparison, and this will be our reference unit throughout the study. Here it is important to always take into account the role of our functional unit, since this must be measurable (quantifiable); this will be a fundamental part of the indicator (Hauschild et al., 2018; International Organization for Standardization, 2006a, 2006b). For example, production of 1kg of cotton for the creation of our t-shirts could be our functional unit.
b) **Unit process**: this is a component of production (quantified during the LCIA phase) that refers to the performance of an action, typically involving a transformation or alteration in which both input flows and output flows participate (Hauschild et al., 2018;

[15] "Energy flow: input or output from a unit process or product system, quantified in energy units; Intermediate flow: product, material or energy flow occurring between unit processes of the product system being studied; Product flow: products entering from or leaving to another product system; Reference flow: measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit" (International Organization for Standardization, 2006a, pp. 10, 11, 12, 13)

[16] "Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product.(International Organization for Standardization, 2006a, p. 12)

[17] "Quantified performance of a product system for uses as a reference unit."(International Organization for Standardization, 2006a, p. 11).

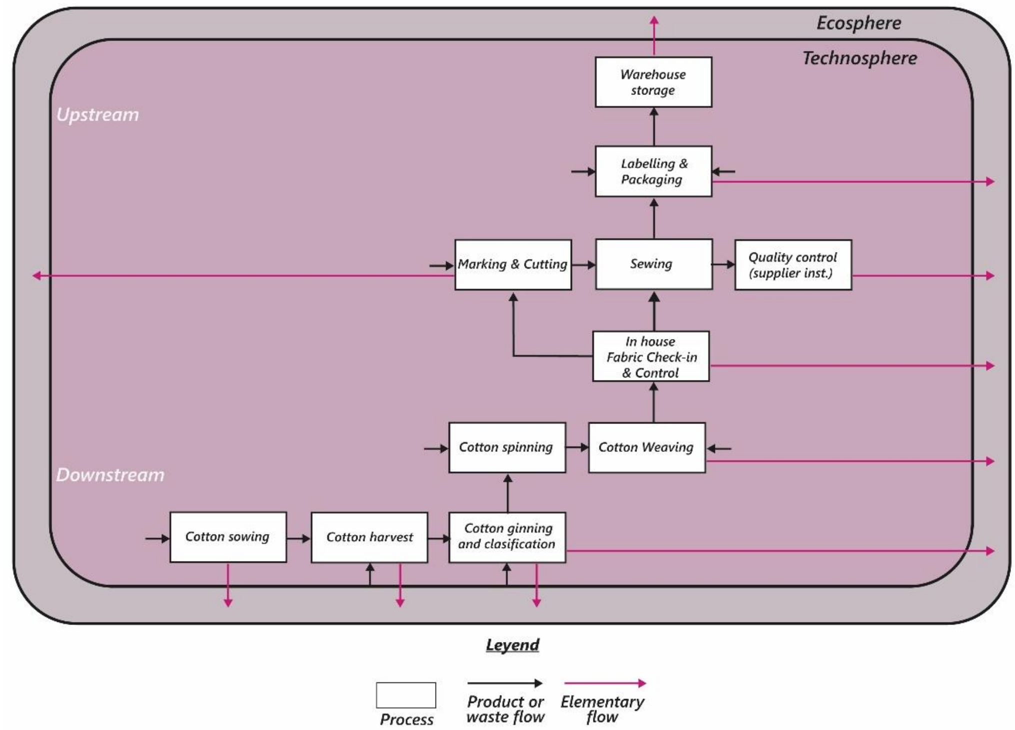
[18] "Class representing environmental issues of concern to which life cycle inventory analysis results may be assigned."(International Organization for Standardization, 2006a, p. 14).

[19] "Specification of the amount of material or energy flow or the level of environmental significance associated with unit processes or product system to be excluded from a study."(International Organization for Standardization, 2006a, p. 11)

International Organization for Standardization, 2006a). For example, the spinning of cotton after its ginning process is considered a unit process.

c) **Product system**: this is the union of several unit processes (being able to incorporate hundreds of processes), where we evaluate the different flows involved and their behavior within this system, specified as a result of the reference flows[20]. It is therefore very possible that this product system can be seen as a representation of the supply chain from the raw material to the stipulated limit (warehouses, points of sale, end of life, recycling...) (Hauschild et al., 2018; International Organization for Standardization, 2006a). For example, a more detailed version of Figure 2 (Figure 6) is found below, demonstrating the incorporation of certain grouped process units such as the cultivation of raw material (sowing, harvesting ...) as well as other processes such as cotton spinning and the various flows within the manufacturing of t-shirts from fabric.

*Figure 6. Product system of a cotton t-shirt.*




Source: adapted from Hauschild et al. (2018).

a) **Boundary System**: each step, process, point and metric within an LCA study are respectively co-dependent, as it is not possible to change only one factor without altering the study to a greater or lesser extent. However, one of the relationships where this interdependence becomes evident is the one that develops in terms of the product system and its boundary system. On the one hand, the product system is responsible for demarcating or mapping each of the processes that interfere within the production process of our functional unit. On the other hand, the boundary systems are the ones that will settle the general limits of the study, which cannot be exceeded by our product

[20] "Measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit"(International Organization for Standardization, 2006a, p. 13)

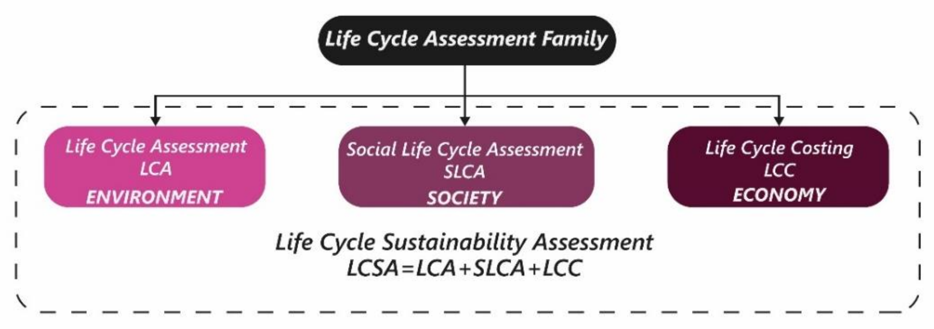
system (except for the elementary flows[21]). The complexity and importance of setting up and choosing these boundary systems appropriately will be explained in greater depth later.

While there are undoubtedly many other factors to consider, for the purposes of this work, only these factors will be discussed. The intention is to supply a general understanding of the tool and the key characteristics that make it an effective means for improving the sustainability of companies operating within the fashion industry.

Furthermore, as mentioned above, the LCA is a method, or rather a "family of tools," as can be observed in the images below (Figures 7 and 8). It encompasses different methodologies with similar characteristics but focuses on different complementary fields, as explained in the next section. Together with other tools, it can present a complete analysis panorama.

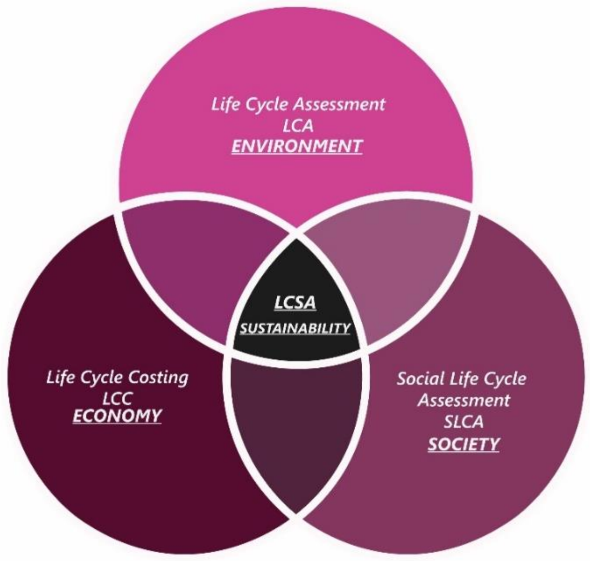
[21] "Material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation"(International Organization for Standardization, 2006a, p. 10)

*Figure 7. Life Cycle Assessment Family*




Source: own creation (2023).

*Figure 8. Life Cycle Sustainability Assessment & TBL.*




Source: own creation (2023).

Of course, as a methodology that incorporates many others, the list itself is much more extensive and may include Life Cycle Thinking Assessment (LCTA), Water Life Cycle Assessment (WLCA), Energy Life Cycle Assessment (ELCA), Waste Life Cycle Assessment (WLCA), etc. But, as it can be seen, all of these tools derive in some form from the three fundamental pillars of the LCA "overall family" (Hauschild et al., 2018).

### 4.1.1 Life Cycle Sustainability Assessment (LCSA) / Sustainability Life Cycle Assessment (SLCA)

As it can be deduced from the previous graphs (figure 7 and figure 8), the LCSA is the union of three different methodologies following the triple bottom line scheme. However, it is probably one of the least known methodologies since it was the first to be born; therefore, the known pioneer within the family is the LCA. Quoting Hauschild et al., "*LCSA is much less mature than LCA and there is a little agreement of how to actually perform it*"(Hauschild et al., 2018, p. 68).

### 4.1.2 Social Life Cycle Assessment (SLCA)

As its name indicates, SLCA seeks to quantify the social impacts associated with the life cycle of a product / service and its system, according with the **Guidelines for Social Life Cycle Assessment of Products and Organizations 2020.** "*S-LCA is one of three methodologies that have been developed to assess the sustainability of the three Pillars of organizations, products and services, focusing on the People Pillar*"(UNEP, 2020, p. 16). It is one of the most innovative methodologies even though it is only in its "infancy," since it is still being developed to study and quantify many complex challenges. Generally, it deals most closely with the violation of human rights, labor rights, children's rights, all kinds of injustices (interracial, gender, generational... etc.), wage issues and other social issues that arise from different economic models and supply/value chains of a product/service (Hauschild et al., 2018; UNEP, 2020).

### 4.1.3 Life Cycle Cost (LCC)

At first it may seem that this section is only to analyze the economic part within the life cycle assessment of a product/service or a system, in accordance with the Guidelines for Social Life Cycle Assessment of Products and Organizations 2020: "*Life Cycle Costing (LCC) focuses primarily on the direct and indirect costs and benefits from economic activities from Profit*"(UNEP, 2020, p. 16). However, the LCC is much more complex, as it is divided into three variants: financial LCC (f-LCC), also called conventional LCC, closer to the Total Cost of Ownership; Environmental LCC (e-LCC), which is the closest to the LCA since it is managed in a similar way in terms of its methodology phases; Societal LCC (s-LCC), where it seeks to have an approach closer to how monetization is managed in terms of externalities and their consequent effects on society (Hauschild et al., 2018; UNEP, 2020).

## *4.2 Boundary system in Life Cycle Assessment (life cycle boundaries)*

Just as suppliers can be divided into tiers, life cycles can be divided based on the amount of data collected from a certain section of the chain. This is known as the boundary system, which involves delineating the boundary of a supply chain, limiting the stages or phases examined during the life cycle of a product, service, process, or system, and fixing a scope to be more efficient. Generally, these boundaries seek to demonstrate hypotheses or answer previously established theories by professionals with experience in fields such as scientific research, engineering, or chemistry, rather than from a managerial perspective, which is the focus of this thesis.

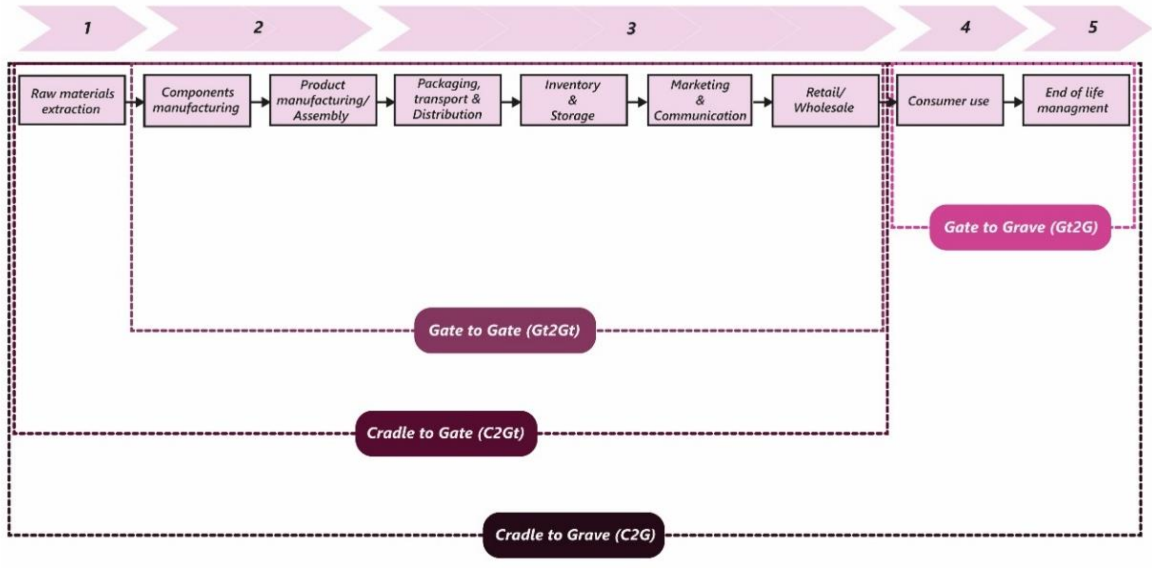
Usually, this system is approached by dividing the supply chain into 5 phases:

1) Extraction of raw materials
2) Production/Manufacturing
3) Packaging/Transport and distribution
4) Consumer use
5) End of life

Although, as we can see in the image below (Figure 9), these phases can contain more than one process, since, as we have previously mentioned, supply chains are much more complex than they appear. Moreover, in the same image, we can see the four most used phases:

i. Cradle-to-Grave (C2G)
ii. Cradle-to-Gate (C2Gt)
iii. Gate-to-Gate (Gt2Gt)
iv. Gate-to-Grave (Gt2G)

*Figure 9. Boundary systems.*



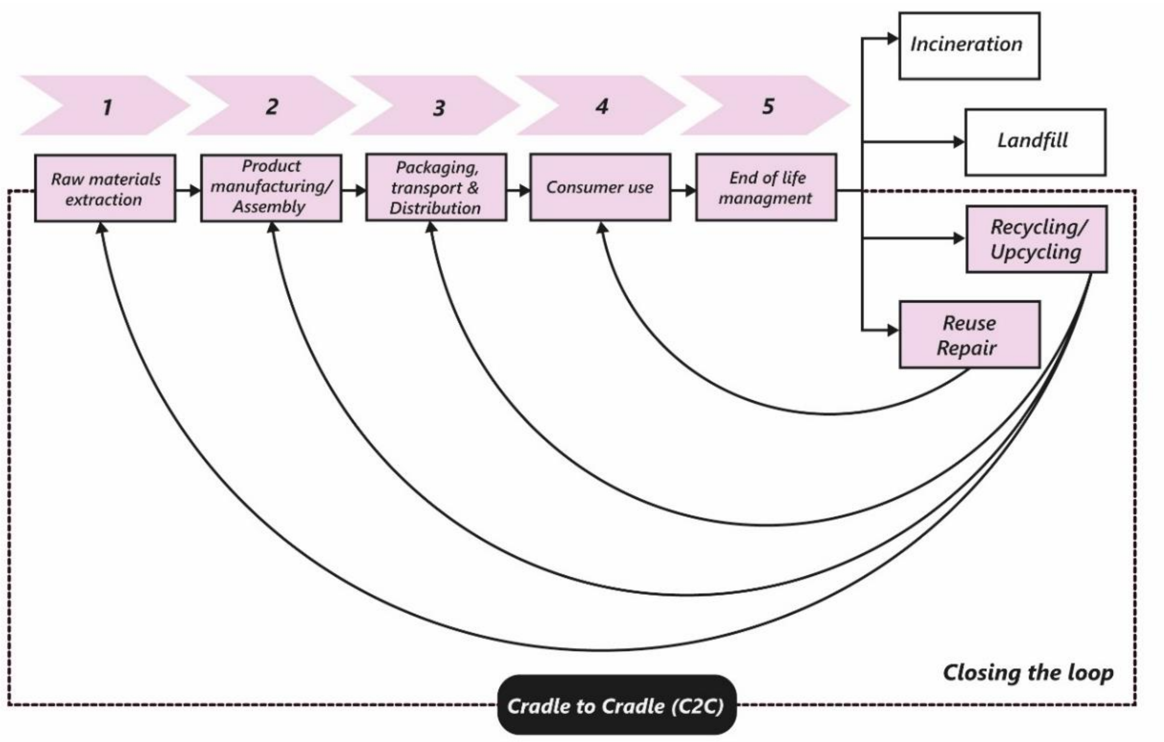

Source: own creation (2023).

However, there is a system boundary that is becoming increasingly relevant for studies, which is probably one of the most important to support hypotheses and theories related to the growing concern and interest of the sector about **the circular economy**[22]: **eco-design**[23] and sustainability. We talk about **closing the loop** through the **cradle-to-cradle approach**, reflected in the following image (figure 10).

[22] "An economic system whereby the value of products, materials and other resources in the economy is maintained for as long as possible, enhancing their efficient use in production and consumption, thereby reducing the environmental impact of their use, minimising waste and the release of hazardous substances at all stages of their life cycle, including through the application of the waste hierarchy"(EFRAG, 2022, p. 11)

[23] "Ecodesign is a proactive approach to environmental management during product development, with the aim of integrating environmental considerations into the product development process. The goal is to minimise environmental impacts throughout the product's life cycle, without compromising other essential criteria such as performance, functionality, aesthetics, quality and cost"(Hauschild et al., 2018, p. 546)

*Figure 10. Boundary systems and Cradle-to-Cradle (C2C) approach.*




Source: own creation (2023).

Given the importance of both the Cradle-to-Grave system and the Cradle-to-Cradle system, the first one is one of the most commonly used for LCA studies, as well as the main system that encompasses the other three (C2Gt, Gt2Gt and Gt2G), whereas the second is gradually positioning itself as one of the most important approaches within supply chains. Let us delve a little deeper into these two concepts.

### 4.2.1 Cradle to Grave (C2G)

The Cradle to Grave (C2G) system aims to analyze the potential impacts of a product throughout its entire life cycle, starting from the extraction of raw materials or the "**cradle**" and ending with its **disposal**, which typically occurs in a **landfill, incinerator**, or through other means such as **upcycling** or **recycling**. The system boundary is defined by the point at which the product is discarded, as it has reached the **end of its useful life** and is considered to be in the "**grave**" stage. Hauschild et al note that: "*A 'cradle to grave' LCA study can provide valuable insight regarding which stages dominate the impacts throughout a product life cycle. Some of these life cycle stages, however, may not be relevant or may be assumed to be equal in two compared systems depending on the goal and scope, and the product system under study*" (Hauschild et al., 2018, p. 792).

On the other hand, while the C2G system is the most comprehensive among the available options (excluding the C2C approach), it is important to note that **a large amount of data is discarded when working with system boundaries**, both during data collection and analysis. As a result, any information external to the boundaries (known as cut-off) may introduce **bias**, which must be addressed by **objective criteria** and **proper controls** in order to explain **why something is not included in the study** (Hauschild et al., 2018; Muthu & Textile Institute, 2015).

### 4.2.2 Cradle to Cradle (C2C)

The C2C approach is a **positive and ecodesign-driven vision** that promotes a circular economy. This approach involves restructuring both designs and processes so that products have characteristics that **improve their quality, usability, and recyclability**, as well as characteristics that **extend their life cycle**. Once a product has reached the end of its useful life, it can be used as a resource for creating other products in a new life cycle (**second useful life**), or in the production of another new product, incorporating upcycling practices. This approach is significant due to the fact that it highlights the problem of **resource scarcity** and the increase in **waste generation**. By following the concept of **waste hierarchy**[24] and working in a separate way, the industry can gradually transition to a more sustainable and circular future.

The relationship between C2C and LCA methodologies is complementary. **C2C aims to increase positive impacts, while LCA aims to reduce negative impacts**. Therefore, if we follow a C2C approach within our business model, and we conduct LCA studies to check the impacts that we have, it will be possible to develop more efficient and effective strategies. Regardless of which business model or economic model we follow, **there are always positive and negative impacts that need to be addressed**. By combining the principles of these two methodologies, we can **reinforce** the positive and reduce the negative impacts, leading to a more sustainable horizon (European Commission, 2022; Hauschild et al., 2018; Muthu & Textile Institute, 2015).

## *4.3 Life cycle assessment and its relationship with sustainable development goals (SDGs)*

**The Sustainable Development Goals (SDGs)** are presented as a list of 17 goals with 169 targets, each one of them **interdependent** to a greater or lesser extent, to direct society towards sustainability.

The connection between the LCA method and the SDGs is even stronger than expected, as demonstrated by previous research done by the **Joint Research Centre (JRC)**[25]. This research highlights the **direct correlation** between LCA indicators, SDGs, and **Planetary Boundaries (PBs)**[26]. The relationship between these elements can provide valuable insights for the European Union as it develops sustainable policies and strategies, aligned with various plans and projects like the European Green Deal and the New Circular Economy Action Plan. While JRC's research is not fashion-specific and focuses mainly on environmental aspects, it provides a **crucial foundation for understanding the relationship between the LCA methodology and the SDGs**. As Sanyé-Mengual et al illustrates, "*The potential use of LCA for monitoring the SDGs was recently explored in the literature*" (Sanyé-Mengual & Sala, 2022, p. 2). It is necessary to emphasize that just as the LCA can write down possible hotspots within the different impact categories, **the other methodologies** within the family (SLCA, LCC ...) **have the same close relationship with the SDGs** (Sanyé Mengual et al., 2023; Sanyé-Mengual & Sala, 2022).

Therefore, it is important to graphically prove the existence of a relationship between the LCA and SDGs. For this reason, tables have been developed relating LCA (Table 1), the SLCA (Table 2)

[24] "The waste hierarchy is the following priority order in waste prevention and management: (a) prevention; (b) preparing for re-use; (c) recycling; (d) other recovery, e.g., energy recovery; and (e) disposal"(EFRAG, 2022, p. 30)

[25] "The Joint Research Centre provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society" (Join Research Centre , n.d.).

[26] "This concept allows to estimate a safe operating space for humanity with respect to the functioning of the Earth. The boundary level for each key Earth System process that should not be transgressed if we are to avoid unacceptable global environmental change, is quantified"(EFRAG, 2022, p. 22).

and LCC (Table 3) to the SDGs, with corresponding targets and interconnected indicators between both sections, as can be seen in the tables below.

*Table 1. Relationship between the LCA and the SDGs.*

| LCA METHODOLOGY | | SDGs | |
|---|---|---|---|
| *LCA (Environment) Impact Categories* | *LCA Indicator* | *SDG Goal & Target* | *SDG Indicator* |
| Climate change | Carbon intensity | SDG 13: Climate action (target 13.2) | 13.2.2 Total greenhouse gas emissions per year |
| Water use | Water use efficiency | SDG 6: Clean water and sanitation (target 6.3) | 6.3.1 Proportion of domestic and industrial wastewater flows safely treated |
| Depletion of the ozone layer | Biodiversity impact | SDG 15: Life on land (target 15.5) | 15.5.1 Red List Index |
| Land use | Land use intensity | SDG 15: Life on land (target 15.3) | 15.3.1 Proportion of land that is degraded over total land area |
| Resource depletion | Material footprint | SDG 12: Responsible consumption and production (target 12.2) | 12.2.1 Material footprint, material footprint per capita, and material footprint per GDP |
| Human toxicity, cancer | Carcinogenic impact | SDG 3: Good health and well-being (target 3.4) | 3.4.1 Mortality rate attributed to cardiovascular disease, cancer, diabetes or chronic respiratory disease |
| Human toxicity, non-cancer | ReCipe human toxicity | SDG 6: Clean water and sanitation (target 6.2) | 6.2.1 Proportion of population using (a) safely managed sanitation services and (b) a hand-washing facility with soap and water |
| Acidification (Water) | ReCipe acidification | SDG 14: Life below water (target 14.3) | 14.3.1 Average marine acidity (pH) measured at agreed suiteof representative sampling stations |
| Freshwater eutrophication | ReCipe Freshwater eutrophication | SDG 14: Life below water (target 14.1) | 14.1.1(a) Index of coastal eutrophication; and (b)plastic debris density |
| Abiotic depletion | Abiotic depletion potential | SDG 7: Affordable and clean energy (target 7.3) | 7.3.1Energy intensity measured in terms of primary energy and GDP |

Source: own elaboration from Sanyé-Mengual & Sala, 2022; UNEP,2020; United Nations, 2022.

*Table 2. Relationship between the SLCA and the SDGs.*

| LCA METHODOLOGY | | SDGs | |
|---|---|---|---|
| *SLCA (Society) Impact Categories* | *SLCA Indicator* | *SDG Goal & Target* | *SDG Indicator* |
| Ethical practices | Supply chain transparency | SDG 12: Responsible consumption and production (target 12.6) | 12.6.1 Number of companies publishing sustainability reports |
| Child labour | Child labor risk | SDG 8: Decent work and economic growth (target 8.7) | 8.7.1 Proportion and number of children aged 5–17 years engaged in child labour, by sex and age |
| Working conditions | Workers rights | SDG 8: Decent work and economic growth (target 8.5) | 8.5.2 Unemployment rate, by sex, age and persons with disabilities |
| Health and safety | Psychosocial well-being | SDG 3: Good health and well-being (target 3.4) | 3.4.2 Suicide mortality rate |
| Gender equity | Representation in managment | SDG 5: Gender equality (target 5.5) | 5.5.2 Proportion of women in managerial positions |
| Poverty | Income level | SDG 1: No poverty (target 1.4) | 1.4.1 Proportion of population living in households with access to basic services |
| Wage assessment | Living wage | SDG 8: Decent work and economic growth (target 8.5) | 8.5.1 Average hourly earnings of employees, by sex, age, occupation and persons with disabilities |
| Community health and well-being | Social cohersion | SDG 12: Responsible consumption and production (target 12.8) | 12.8.1 Extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment |
| Local economies and employment | Accessibility and mobility | SDG 11: Sustainable cities and comunities (target 11.2) | 11.2.1 Proportion of population that has convenient access to public transport, by sex, age and persons with disabilities |
| Access to education | Literacy rates | SDG 4:Quality education (target 4.6) | 4.6.1 Proportion of population in a given age group achieving at least a fixed level of proficiency in functional (a) literacy and (b) numeracy skills, by sex |

Source: own elaboration from UNEP, 2020; United Nations, 2022; Zamani et al., 2018.

*Table 3. Relationship between the LCC and the SDGs.*

| LCA METHODOLOGY | | SDGs | |
|---|---|---|---|
| *LCC (Economy) Impact Categories* | *LCC Indicator* | *SDG Goal & Target* | *SDG Indicator* |
| Water use costs | Investment on water efficiency | SDG 6: Clan water and sanitation (target 6.4) | 6.4.1Change in water-use efficiency over time |
| Waste managment costs | Waste ratio | SDG 11: Sustainable cities and comunities (target 11.6) | 11.6.1 Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal waste generated, by cities |
| Recycling revenues | Recycling rate | SDG 12: Responsible consumption and production (target 12.5) | 12.5.1 National recycling rate, tons of material recycled |
| Health and safety | Exposure to hazardous materials | SDG 3: Good health and well-being (target 3.9) | 3.9.2 Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene (exposure to unsafe Water, Sanitation and Hygiene for All (WASH) services) |
| Transport costs | Percentage of transport by means of transport | SDG 9: Industry, innovation and infraestructure (target 9.1) | 9.1.2 Passenger and freight volumes, by mode of transport |
| R&D costs | Investment on R&D | SDG 9: Industry, innovation and infraestructure (target 9.5) | 9.5.1 Research and development expenditure as a proportion of GDP |
| Cost of emissions | Direct emissions | SDG 9: Industry, innovation and infraestructure (target 9.4) | 9.4.1 CO2 emission per unit of value added |

Source: own elaboration from UNEP, 2020; United Nations, 2022.

Information from different sources has been used to prepare the tables, predominantly from the following documents: *Life Cycle Assessment support to environmental ambitions of EU policies and the Sustainable Development Goals* by Sanyé-Mengual et al, the *United Nations report of Global indicator framework for the Sustainable Development Goals and targets* of the 2030 Agenda for Sustainable Development Goals and Targets (from the 2030 Agenda for Sustainable Development), the *Guidelines for Social Life Cycle Assessment of Products and Organizations* from the United Nations Environment Programme, and the *Hotspot identification in the clothing industry using social life cycle assessment—opportunities and challenges of input-output modelling* from Zamani et al (Sanyé-Mengual & Sala, 2022; UNEP, 2020; United Nations, 2022; Zamani et al., 2018).

Here should be mentioned that the first table (Table 1) is primarily (but not solely) based on the work of Sanyé Mengual & Sala, and thanks to this work, it was possible to develop the following tables (Table 2 and 3) by adapting them and gathering information from other previously mentioned sources, as well as investigating other cited documents.

While Sanyé Mengual & Sala's work has been a significant inspiration and holds a higher level of validation compared to this present document, it is important to clarify that the aim of this section is not to claim pioneering status in the relationship between SDG indicators and LCA analyses. Instead, this section serves as an interpretive continuation of their work, building upon a range of robust and scientifically validated sources. The primary objective is to highlight the critical interplay between the SDGs and the various categories of LCA (SLCA and LCC), going beyond the traditional environmental LCA perspective. This document offers a conscientious interpretive perspective, recognizing its reliance on multiple texts and sources. Moving forward, it becomes imperative to employ more robust and preferably regulated methodologies to achieve a comparable level of recognition as Sanyé Mengual & Sala's work.

It is important to note that the relationship between the LCA and the SDGs, while significant, is **complex and influenced by several factors**. Some of these factors can be the LCIA method used, the study location, the selected period, the system boundary, and the cut-off criteria. All of this influences the relationship between impact categories and SDGs goals and targets. However, while the **SDGs were developed as a tool guide for countries**, companies can also use them to assist in achieving these goals on a smaller scale. This is why the indicators suggested by the organization have continued to be used, albeit with a more micro-scale perspective.

# 5. Life Cycle Assessment (LCA) in the textile industry

In previous sections of this study, the following topics have been addressed:

a) The complexity of supply chains within fashion.
b) The relevance of the structural organization of a supply chain and its breakdown by tiers.
c) The importance of choosing the proper criteria, including cut off criteria, along with their boundary system for study purposes.
d) Understanding that the LCA is composed of several methodologies, with both common general and specific characteristics. Each one of them focus on different aims, although these may be interconnected.
e) The interconnectivity between the LCA and the SDGs.

Now, it is necessary to delve deeper into the fashion industry supply chain by analyzing different viewpoints on the implementation of LCA. Additionally, the Kering case study will be presented to display the multifaceted perspective that the same tool (LCA) can offer. There are infinite possibilities in which this tool can be used, based on which criteria are chosen and on the respective aim of the assessment. This will reinforce the idea that the LCA is slowly but progressively gaining followers within the fashion industry.

## *5.1 A focused review of perspectives and connecting threads on fashion industry supply chains for Life Cycle Assessment (LCA)*

The following articles have been selected considering the need to cover a holistic view in the fashion industry's supply chain, as well as diverse materials relevant to the study. Since the results can be significantly influenced by the material chosen and the specific step along the whole supply chain for the study, these research papers have been chosen from a relatively larger list, taking into account other determining factors such as: their publication year, study location, level of complexity, their relevance, validity, contribution to the research topic and complementarity between them.

Given the complexity of each supply chain and its interconnected links, it is imperative to understand that many companies work in parallel (Rossi et al., 2021). Therefore, some of these industries act not only as suppliers/producers but also as buyers, simultaneously. In order to understand the diversity and complexity of supply chains involved in the fashion industry and their interconnections from an LCA perspective, a focused bibliographic review of eight LCA studies specific of the fashion industry has been undertaken. All studies except for one -that deals with SLCA- focus on LCA within the LCA family of tools. As regard to the type of boundary system, 5 studies take a Cradle to Gate approach (CtGt), two focus on Cradle to Grave (C2G), and only one covers Cradle to Cradle (C2C). The next figure (Figure x) synthesizes results of the focused literature review in terms of topics and type of LCA methodology and boundary system. Next, a description of highlights from each of the studies follows.

*Table 4. Focused literature review: LCA methodology associated to each study, main topic, and boundary system.*

| Authors | LCA methodology | Main topic | Boundary system |
|---|---|---|---|
| Rossi et al. 2021 | LCA | Leather | Cradle-to-Gate (C2Gt) |
| Chen et al. 2021 | LCA | Cotton | Cradle-to-Gate (C2Gt) |
| La Rosa et al. 2019 | LCA | Cotton | Cradle-to-Gate (C2Gt) |
| Liu et al. 2020 | LCA | Melange Yarns | Cradle-to-Gate (C2Gt) |
| Wiedemann et al. 2021 | LCA | Wool | Cradle-to-Grave (C2G) |
| Sohn et al. 2021 | LCA | Consumer behaviour | Cradle-to-Grave (C2G) |
| Hauschild et al. 2021 | LCA | Closing the loop | Cradle-to-Cradle (C2C) |
| Zamani et al. 2018 | SLCA | Social hotspots | Cradle-to-Gate (C2Gt) |

Source: own creation (2023)

## Life cycle assessment of a leather shoe supply chain (Rossi et al. 2021)

The first article provides an analysis of potential environmental impacts throughout the supply chain of a pair of leather boots. The study uses a **Gate-to-Gate** system, which includes the consideration of hide sacrifice and tanning processes (Rossi et al., 2021). However, the authors mention several facts that may be of vital importance for future discussions. For example, the authors highlight the following aspects of the process that must be considered, listing "*the most impactful phases for the analysed supply chains, i.e., slaughterhouse, tanning, shoe manufacturer, and shoe upper manufacturer*" (Rossi et al., 2021, p. 14). At the same time, they emphasize that **the process of animal husbandry is not considered in the study**, despite leather production being a by-product of the supply chain of livestock and meat industries. This is **one of the most polluting phases** of what will become the **main raw material of the leather industry**.

## A review: Life cycle assessment of cotton textiles (Chen et al. 2021) and a Comparative Life Cycle Assessment of Cotton and Other Natural Fibers for Textile Applications (La Rosa et al. 2019)

Meanwhile, if the presence of cotton within the supply chain is taken into consideration, either in special sections of footwear or packaging, it is necessary to note how different materials are required in production, even if they are not the main raw material or part of the final product (Rossi et al., 2021). (Rossi et al., 2021, p. 14)This leads us to develop the second and third articles, since **the main topic is cotton**. We found a review and alternatives to traditional cotton cultivation, along with its potential replacements, respectively.

Before continuing, it should be emphasized, along the lines of Chen F. et al., that "*This methodology should be studied and developed further to more precisely evaluate the environmental impacts of cotton textiles*" (Chen et al., 2021, p. 1). So, while these articles are interesting, they stand for a brief introduction to a much more complex topic: the **cotton supply chain**. This highlights the significance of cotton in **assessing environmental impacts**, as it has been identified as a crucial factor in multiple studies for three primary reasons:

It is **one of the most used fabrics worldwide**, as "*The global cotton trade ensues that most of the cotton produced in a region is actually utilized in another*" (Chen et al., 2021, p. 2). The global nature of cotton production prioritizes countries with high environmental risks, particularly in **underdeveloped or resource-deprived nations.** According to Chen et al. " *India, China, the United States, Brazil, and Pakistan, which are the main producers of cotton and account for more than three quarters of global cotton pro-duction*" (Chen et al., 2021, p. 2). At the same time, La Rosa et al demonstrate that in terms of cotton cultivation "*it is restricted to sub-tropical climates, and it is dependent upon high amounts of water, as well as the use of agrochemicals to ensure good yields. The use of pesticides and other types of chemical products give a negative impact on the environment*" (La Rosa & Grammatikos, 2019, p. 1).It is important to prioritize the understanding of the **use and applications of cotton** as it is a **dynamic material** that is used in **various industries beyond textiles**, such as the automotive industry, construction, food, and more. But it is also important to understand its supply chain logistics and production processes, as Chen F. et al. point out that "*The entire life cycle of cotton textiles is long and complex, and includes cotton cultivation and harvest, manufacture (ginning, spinning, weaving, dyeing, cutting and sewing, and ironing), consumption (retail and use), and disposal*" (Chen et al., 2021, p. 1). **Each of these links has its own supply chains and processes**. Therefore, understanding the reason for each step is crucial for sustainability and efficiency, which will not only help the textile industry but also other industries where cotton is used. Life cycle assessment of melange yarns from the manufacturer perspective (Liu et al. 2020)

In addition to cotton, it is imperative to consider other materials such as **threads and yarns**, which are essential components of all fabrics. The fourth article supplies a closer look at the manufacturers in this industry, specifically those producing **melange yarns**[27]. Liu et al comment that the study "*focuses on evaluating the environmental impacts of melange yarns spun from different coloured fibres and identifying the environmental hotspots, in order to seek opportunities for improvement from the manufacturer's perspective*" (Liu et al., 2020, p. 1). This study stands out above the others, due to the depth to which Liu et al explain the following: "*Melange yarns have a unique dyeing process with a small liquor-to-fibre ratio (generally less than 10:1) which can reduce material consumption compared with yarn dyeing or fabric dyeing, in terms of dye stuffs, auxiliaries, and water consumption. A study has confirmed that the production growth rate of the melange yarns will be higher than that of the regular yarns*" (Liu et al., 2020, p. 2).

This approach does not diminish the importance of melange yarn production, but rather looks to **understand how distinct colors can have varying environmental impacts**, which could inform a redesign of the industry towards eco-design. It highlights the need to **find which types of threads are most suitable for large-scale** production **and which ones require stricter controls** due to their higher environmental risks.

The discovery that **colors have a certain effect on each fabric** and design is not an isolated fact from the perspective of designers. Therefore, it should not be surprising that consumption of resources, production processes, and properties are altered by something as "simple" as color.

[27] "Mélange or grey melange yarn may be defined as "the yarn produced by the combination of at least two or more than two fibers". Conventionally, the term melange is used for such yarns which are produced by the combination of two fibers (whether of same type but different in color or type of fiber used is different) "(Islam Kiron, 2021).

The authors themselves make it noticeably clear that many yarns used are "*Melange yarns spun from different proportions of colored fibers which have different energy consumption and emissions. Therefore, it is necessary to assess environmental impacts of melange yarns considering the color of fibers*" (Liu et al., 2020, p. 2).

Environmental impacts associated with the production, use, and end-of-life of a woolen garment (Wiedemann et al. 2021)As previously discussed in the Rossi et al. article on leather production, we can see that another part of the industry follows a similar pattern of possible risks and environmental impacts in various stages of its supply chain, particularly in the **upstream sections**. The fifth article delves into the environmental impacts linked to **the production of woolen garments**. As Wiedemann et al point out: "*To date, there have been limited life cycle assessment (LCA) studies on the environmental impacts of the full supply chain or use phase of garments, with the majority of wool LCA studies focusing on a segment of the supply chain"* (Wiedemann et al., 2020, p. 1) which has led the authors to develop a more in-depth study covering the entire life cycle of the product, i.e., under a **Cradle-to-Grave** system.

The **properties** attributed to wool have made it one of the **most coveted raw materials even beyond the fashion sector.** "*Wool grease is an important raw material product with many uses, including high-value pharmaceuticals and cosmetics when refined into lanolin*" (Wiedemann et al., 2020, p. 7) . Similarly, wool garments are known for their longer useful life compared to other fabrics, which is often considered a strength in reducing environmental impacts. However, like cotton, wool's supply chain is complex, with offshoring and significant resource requirements, particularly in the numerous wet and energy-intensive processes needed to develop high-quality fabrics and garments for an increasingly demanding consumer base and industry. It is also important to note that **the environmental impacts vary across the supply chain**, with different impact categories standing out at divergent phases, such as greenhouse gas emissions and water consumption during wool production or high energy consumption during use (directly related to consumer habits) (Wiedemann et al., 2020).

Despite the various stages of production presenting their own risks and consequences, it is **particularly concerning that there is a scarcity of studies** about the phase that corresponds to consumers. This is surprising, considering the importance of **understanding the environmental impacts associated with consumer behavior**, and the need to address it in order to reduce the overall impact of the fashion industry on the environment. As Wiedemann et al. highlight: "*Moreover, the important role of consumers in defining the length of garment lifetime (i.e., the time a garment stays in active use) has not been assessed for woollen garments resulting in an important knowledge gap in this area*" (Wiedemann et al., 2020, p. 2).

While investigating the phase of use and consumption is a **challenging task**, it is a crucial factor in the life cycle assessment of a product. Therefore, more studies focused on consumer behavior are needed to analyze the estimated time of use and the way in which consumers take care of their garments (e.g., through machine washing or drying), as **this directly affects the use of resources and, consequently, the environmental footprint of each garment** (Muthu & Textile Institute, 2015; Wiedemann et al., 2020).

### The environmental impacts of clothing: Evidence from United States and three European countries (Sohn et al. 2021)

Moving on to the sixth article, this study sheds light on consumer behavior and their habits. It is worth noting that these habits aren't limited to just their clothing preferences; rather, it also encompasses other behaviors such as garment use and care, washing, recycling, and even how garments are discarded. **Understanding and analyzing these habits is crucial** in reducing the environmental footprint of the textile industry (Sohn et al., 2021).

To explore the differences in consumer habits and behaviors, the article focuses on **four countries with distinct fashion trajectories**: Germany, a major producer; Poland, an example from another part of Europe; Sweden, which stands out for its interest in sustainability; and the United States, one of the most consumeristic countries with an alternative sense of style compared to Europe (Sohn et al., 2021).

However, the study only focuses on two of the most commonly used garments worldwide - **a pair of jeans and a t-shirt**. Therefore, it could even be considered that there are two analyses in one (Sohn et al., 2021). This represents only the **tip of the iceberg**. If the impacts are so severe for two of the most basic garments that each person has in their wardrobe, which are worn repeatedly, then, what would the implications be for other garments with more complex designs and production processes?

Throughout the lifecycle of some garments, we find a high consumption of water, energy, and chemicals, including maintenance activities such as washing and drying, until the end of their life. Details such as the temperature of the water, the type of detergent used, and the quantity of clothes washed **can stand for significant energy savings or expenditures** (Sohn et al., 2021).Environmental consequences of closing the textile loop-life cycle assessment of a circular polyester jacket (Hauschild et al. 2021)

Moving from the complexity of studying consumer behavior, we meet another challenge in the fashion industry: **designing products that meet the criteria of the circular economy** (CE). In the words of Hauschild et al., "*While the CE approach sounds promising, it is far from obvious if it can make a significant contribution to the design of an environmentally sustainable economy. Several limitations and uncertainties exist that can prevent the environmental superiority of a CE approach over the linear way of today's production [12,13]. For example, a high percentage of recycled materials in a product could reduce the lifetime of that product. Thus, increasing the share of recycled materials does not necessarily lead to a better environmental performance*" (Hauschild et al., 2021, p. 2). The seventh article presents a **comparative analysis between a linear product and a circular product**. This is essential because many studies using LCA have focused on specific impact categories, leading to a narrow focus that may overlook other relevant impact categories. Although many studies have examined products until the end of their life cycle**, no comparison between linear and circular products had been conducted until then**. This study provides valuable data to consider (Hauschild et al., 2021).

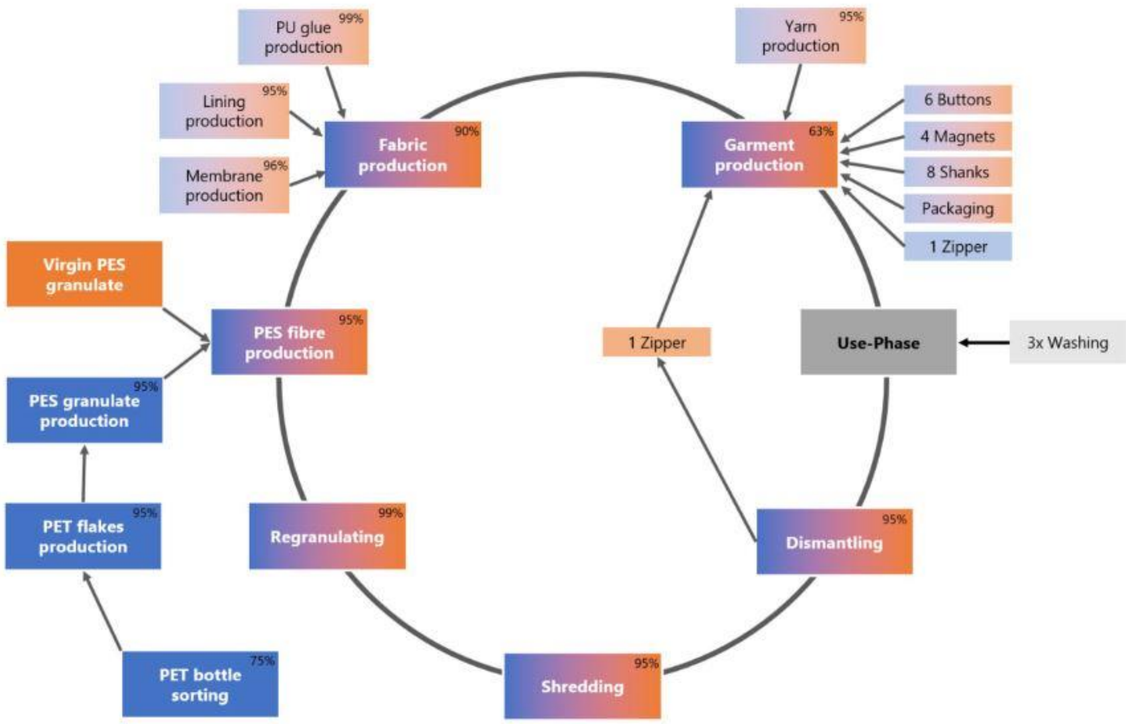
Now, in regard to supplying a more comprehensive overview of the industry, it was necessary to take into account at least one article studying polymeric materials such as PET and PES, given their versatile nature in the fashion industry and others. This article uses a work jacket from the wear2wear[28] initiative as a reference of a circular jacket and compares it to a linear jacket with similar characteristics. Although the jackets share similarities, the authors point out the main differences between the two, which are crucial factors to consider in the study. "*There are three main differences between the circular and linear jacket. The circular version has (1) a fabric that is partly made from polyethylene-terephthalate (PET) bottles while the linear jacket's fabric is made from virgin PES only, (2) a reusable zipper that is removed at the EoL, and (3) a recycling process that regranulates the entire fabric in order to be used for another jacket (so called closed*

[28] "a collaboration consisting of multiple companies aiming to close the loop for polyester textiles"(Hauschild et al., 2021, p. 1).

*loop recycling), instead of being incinerated. Note that the production of PET bottles for the circular jacket have caused environmental impacts themselves when produced*" (Hauschild et al., 2021, p. 2).

In order to fully understand the study, it is helpful to make use of the images presented in the article. Next image (Figure 11) illustrates the process of producing the wear2wear jacket and the differences between the circular and linear models in terms of the percentage of use of each part within the cycle. **The blue section stands for the first loop, while the orange sections represent subsequent loops.** It is important to note that the jacket is estimated to have a **life cycle of 4 years** and is only **washed 3 times**, which has an impact on multiple indicators (Hauschild et al., 2021).

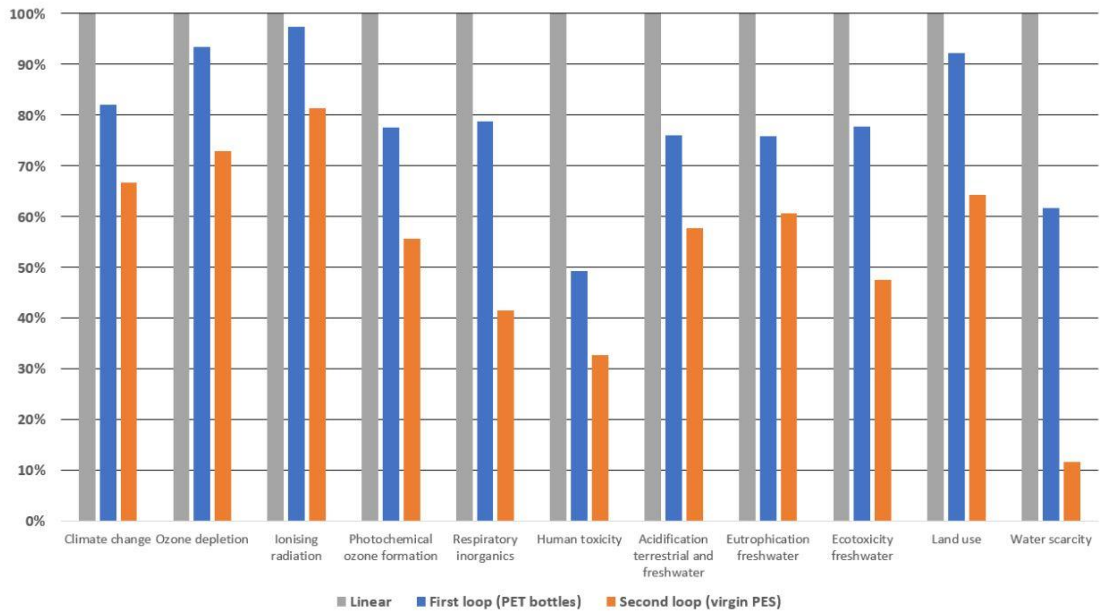
*Figure 11. Multiple wear2wearTM product systems interlinked by recycling and reusing activities.*




Source: Hauschild et al., 2021, p.5 (2021).

To better understand the results of the study, the image below (Figure 12) shows a comparison of the environmental impact between **the linear product system** and **the first and second loop** product systems. The results clearly show that there is a significant difference between linear and circular production, and the benefits become clearer with each added loop. Although the second loop (in orange) uses virgin PET, the negative impact on all indicators shows improvement in resource use and reduction of possible effects, particularly in **respiratory inorganics, ecotoxicity freshwater, and water scarcity**. The reason behind this is that the efficient recycling/upcycling of waste leads to a reduction in **transport, less production of certain pieces (like zippers)** and certain **materials (like less virgin PES)** which will be recycled. Additionally, less material will be incinerated with this best recycle/upcycle process (Hauschild et al., 2021).

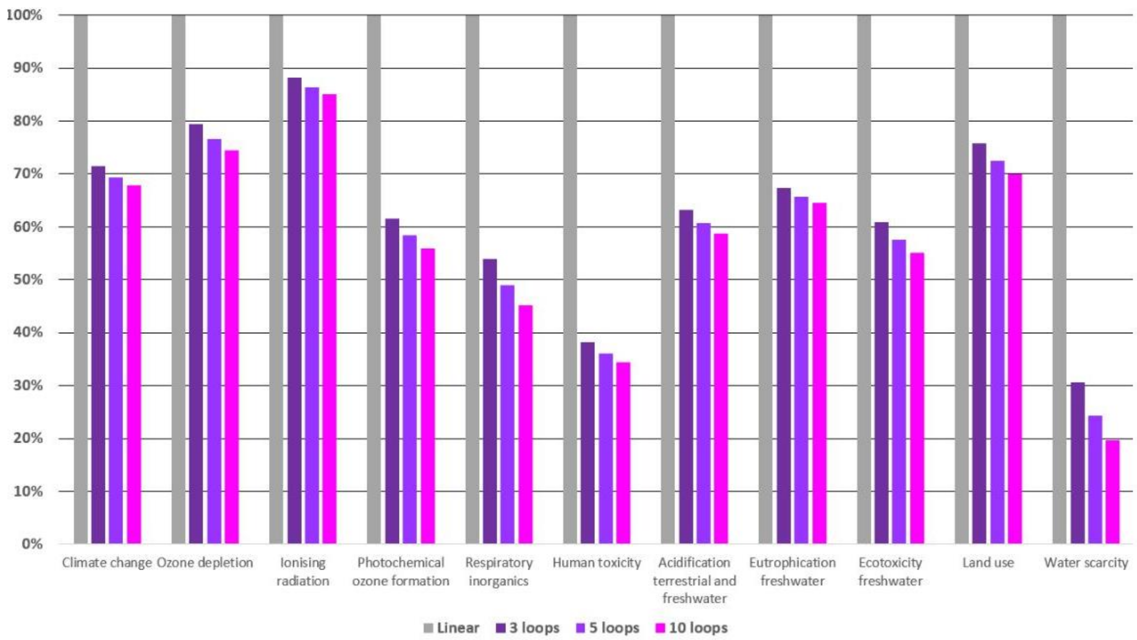
*Figure 12. Environmental impact comparison between the linear product system and the first and second loop product systems.*




Source: Hauschild et al., 2021, p.6 (2021).

Moreover, as we analyze the next loops, we observe **a clear pattern in terms of reducing the jacket's impacts**, adhering to the circular economy's principles, as depicted in the image below (Figure 13). However, while the circular economy has its advantages, as mentioned above, it is essential to note that **recycling processes are still in development**. Therefore, the same material **cannot be repeatedly recycled and reused without losing some of its properties**. Furthermore, **replacing primary materials** is a crucial factor to consider in this study. Citing Hauschild et al., "*the lower impacts of the wear2wearTM jacket come from the fact that the primary materials are substituted by secondary materials from the former loop based on reuse and recycling principles. It is relevant to note that the lower impacts of the wear2wearTM jacket do not come from the utilization of recycled PET from bottles*" (Hauschild et al., 2021, p. 9).

*Figure 13. Environmental impact comparison between one linear product system and the average impacts of three, five and ten wear2wearTM product systems.*




Source: Hauschild et al., 2021, p.8 (2021).

## Hotspot identification in the clothing industry using social life cycle assessment—opportunities and challenges of input-output modelling (Zamani et al. 2018)

Finally, in this section, we have mainly focused on LCA from an environmental perspective. As previously mentioned, this method can broaden the scope of understanding not only for products but also for processes and the entire supply chain system. Therefore, it is important to **briefly touch upon the subject from a social perspective**, given its significance, especially when addressing issues related to sustainability. Furthermore, in the case study, the economic aspect will also be taken into account when we analyze the Kering case study.

In order to analyze the social aspect, a study was chosen that highlights the importance of **pursuing social improvements in current supply chains** in order to achieve sustainability. Citing Zamani et al., "*One of the reasons for the lack of assessments is the difficulty of performing traditional process analysis on long, International and opaque supply chains*" (Zamani et al., 2018, p. 2). These risks can affect various stakeholders across the entire supply value chain, leading to societal consequences. As previously mentioned, sustainability cannot be achieved without pursuing social improvements in supply chains. Such **risks are often related to human rights**, workers' rights, health and well-being, different governance systems, and **the growing issue of corruption**. Additionally, risks related to slavery (**including modern slavery**), forced labor, and child labor can also have significant impacts (Zamani et al., 2018).

The study by Zamani et al. is mainly based on identifying those negative hotspots within the **Swedish textile industry**. The **number of hours worked** associated with the product has been used to evaluate the distinct levels, with **high and very high-risk ratings** representing a **hotspot of risk** depending on each indicator. It should be noted that the authors themselves are aware of the "novelty" of this method, and they acknowledge the lack of bibliography and data at the time of the study. Analyzing and properly finding social indicators **is a challenge** and therefore one of the most important steps for the study, as they have stated it in the document. Finally, the 11 indicators were chosen based on the priorities for Swedish consumers (Zamani et al., 2018).

The document shows that the clothing industry, as it is a large and globally fragmented sector, poses a risk to workers' rights. As mentioned earlier, **relocation** is one of the **primary factors** that makes it challenging to support **appropriate control** over compliance with laws and varying **wage expectations** at different levels of the supply chain (from raw material production to the consumer). This factor also limits the proper use of **bias systems** (cut-off criteria) that **directly influence the results**. Moreover, the document highlights that using only the "high risk" and "very high risk" levels, and extending the margin of the cut-off criteria, could provide more information about other current or potential hotspots that need to be considered (Zamani et al., 2018).

## *5.2 Junctures for Life Cycle Assessment (LCA) in the textile industry.*

### 5.2.1 Consumer use

Understanding the population's consumption habits is a challenging task, as it is necessary to **consider cultural, social, and economic aspects.** Similarly, **the nature of each product** must also be taken into account, as its functionality and characteristics are heavily influenced by this nature. Therefore, showing widespread guidelines for the population is a complex task, but not an impossible one (Muthu & Textile Institute, 2015).

Although only a few LCA studies have included the use and post-consumer phases (such as disposal or more sustainable end-of-life options), these studies have emphasized the **significant impact of the use phase** on life cycle assessment and the quantification of environmental impacts resulting from irresponsible consumption practices (Muthu & Textile Institute, 2015).

Despite that fact, analyzing the behavior of consumers and the way they maintain garments is an elaborate task. It is possible to **identify specific areas of their consumption habits** and patterns that need to be targeted to reduce certain impacts (often related to GHG emissions, various impact categories related to water and energy efficiency and consumption), such as:

- How often a garment is washed.
- How old the garment is.
- Amount of detergent used.
- Water temperature.
- Use of dryer.
- Use of iron.
- Chemicals used in their washing processes (e.g., bleach)
- Characteristics of the garment.
- Type and characteristics of appliances used.

In any case, it is necessary to understand two points:

1) Indeed, **the responsibility** for the diverse ways of consuming and caring for a product **does not solely lie with the consumer**. It is essential that products are designed in a more conscious, practical, and circular manner, while also improving their quality to prolong their lifecycle and avoid being easily discarded. Ecodesign criteria can aid and encourage the transition towards more responsible and efficient consumption patterns (Muthu & Textile Institute, 2015).
2) As already mentioned, there are very few studies regarding this matter. It is not only **necessary to develop many more**, but it is also **urgent** due to the high **relevance and**

**involvement of consumers** in properly quantifying and analyzing the impact of a product throughout its entire life cycle (Muthu & Textile Institute, 2015).

### 5.2.2 Disposal and Recycling

Although the word recycling is well known today, the definition itself encompasses several approaches to recycling with respect to the textile industry. To begin with, we should understand what kind of approach within recycling is the one that our "product" is following:

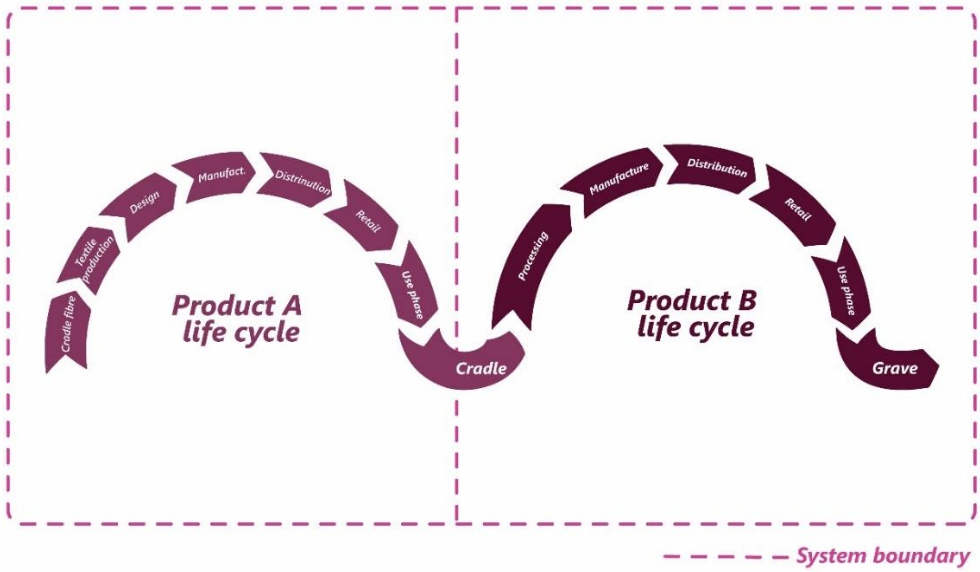
I. **Pre-consumption phase**. What is recycled is the waste and other material left over from the productions. This is still material in a certain "virgin" way since it still has the **original characteristics** of the fabric, although it probably varies in quantities and sizes (Muthu & Textile Institute, 2015).
II. **Post-consumer phase**. Garments and other textiles that have **reached the end of their life cycle** and are no longer useful to the original owner are collected and recycled. These materials can take different paths, such as being donated to non-profit organizations that will repurpose them in different ways depending on the organization, or being sent to recycling facilities to be turned into new products. In some cases, these materials may even be exported to other countries for processing or resale (Muthu & Textile Institute, 2015).
III. **Both the pre-consumer and post-consumer phases** involve recycling and classification of materials. After undergoing various processes, the materials are transformed into new raw materials. This is typically done with polymer-based products, which can have their useful life extended through chemical processes and incorporation into new life cycles. However, such recycling can deteriorate the original composition of the product and affect its performance. Although this is the most common phase for polymeric products, it is also possible to recycle products made of other materials, such as cotton or wool. **Textile recycling is known to be laborious and complex**, especially when recycling mixed fabrics that incorporate various materials into their composition (Muthu & Textile Institute, 2015).
IV. **In both the pre-consumption and post-consumption phases**, incineration is an approach that involves complex issues influenced by various variables and legislations. While it is an interesting topic that may be enriching for future analysis, **it will not be investigated further in this document** (Muthu & Textile Institute, 2015).

Likewise, recycling can be classified into two types, depending on the nature of the product resulting from the recycling approaches that were mentioned earlier:

a) **Open-loop recycling,** also known as open-circuit recycling, is the first classification within recycling. After undergoing various recycling processes, typically associated with **downcycling**[29] as illustrated in the following image, the result is a product generally of **lesser value than the original one** (Figure 14) (Muthu & Textile Institute, 2015).

[29] "If the new product is of lesser economic value."(Muthu & Textile Institute, 2015, p. 106).

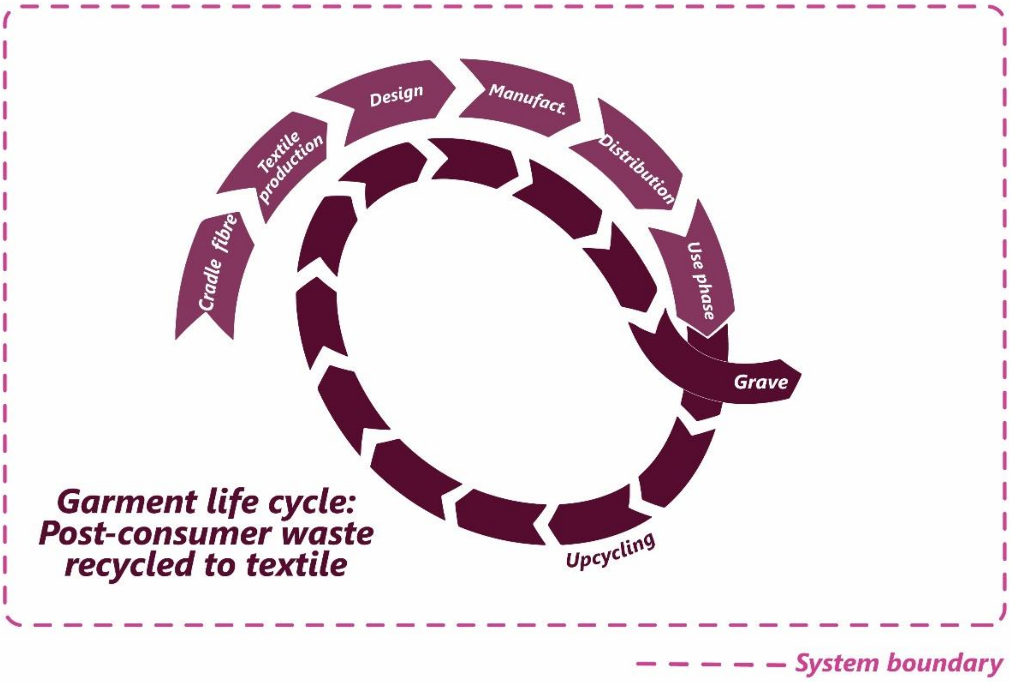
*Figure 14. Open-loop recycling.*




Source: adapted from Muthu & Textile Institute, 2015, P.,107 (2015).

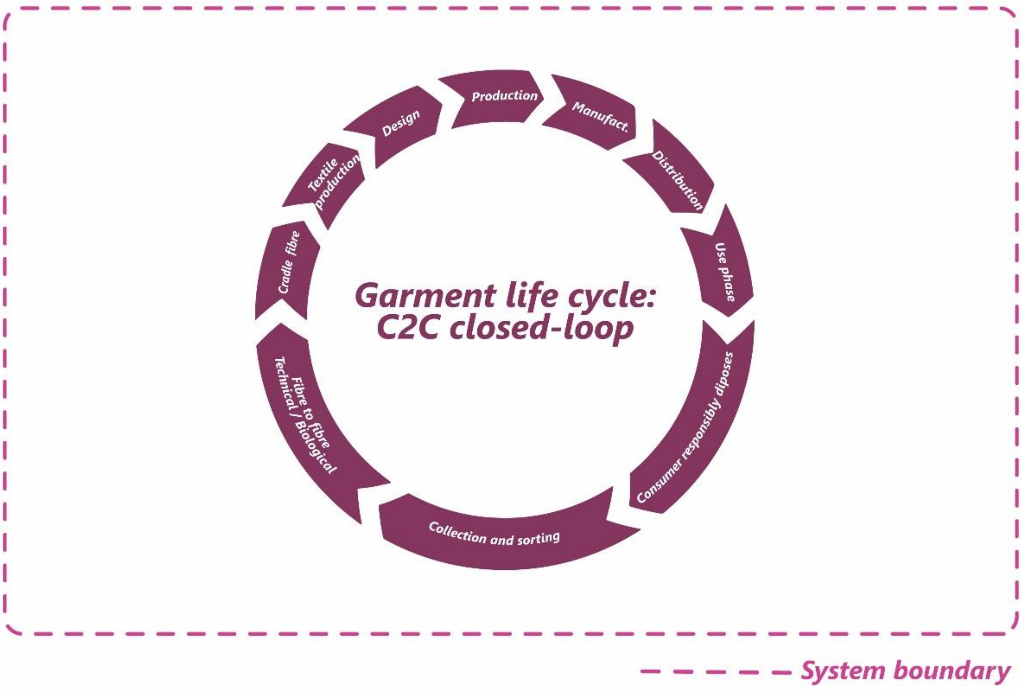
**b)** The second classification within recycling is called **Closed-loop Recycling**. The result after the different recycling processes gives rise to a product with characteristics similar to the original product and may even belong to a new product within the same category. For example, if a 100% cotton shirt is recycled, the resulting recycled cotton can be used to create another new shirt (Muthu & Textile Institute, 2015). Although this classification is much more complex than the previous one, as it can be further divided into different closed loops, it is usually associated with two interconnected terms: **upcycling** and **Cradle-to-Cradle (C2C)**. These closed loops are used to illustrate the difference between the earlier classification, as shown in the images below (Figure 15 and Figure 16). It is important to note, however, that **while these terms are closely related, they are not the same.**

*Figure 15. Post-consumer waste is disassembled in order to reuse the textile.*




Source: adapted from Muthu & Textile Institute, 2015, p., 112 (2015).

*Figure 16. Post-consumer waste in shredded to fibre for reprocessing back to yarn.*




Source: adapted from Muthu & Textile Institute, 2015, p., 113 (2015).

The aim of both classifications is to **extend the useful life of a product** by transforming it from **waste into a new raw material** when it reaches the end of its (first) life cycle. Although each classification has its unique characteristics and limitations, they both serve as recycling systems that **complement each other** and help the transition towards more efficient and circular business models (Muthu & Textile Institute, 2015).

### 5.2.3 Traceability & Transparency in LCA perspective

It is important to note that both traceability[30] and transparency are essential for developing life cycle assessment studies accurately. For practical purposes, we will supply only a brief assessment.

The lack of transparency and traceability, both at the industry level and within individual companies, can have **a significant negative impact** on a brand's business model and its effects on various stakeholders. This can limit a **brand's flexibility and ability to make strategic decisions**. The article "Lifecycle traceability towards Sustainable and circular value chains: analysis framework and state of the art in the fashion industry" by Riemens et al. serves as a reference for analyzing this topic, along with other relevant sources (Riemens et al., 2022).

The relationship between transparency and traceability is **much more profound and significant** than what meets the eye. As noted by Riemens et al., "*Garcia-Torres et al. (2019) recently introduced the concept of "Traceability for Sustainability" (TfS) as "the ability to combine supply chain information sharing and visibility in a way that allows chain actors to have access to information that is accurate, reliable, timely, and useful for their operations and for the reliability of sustainability claims*" (Garcia-Torres et al., 2019, apud Riemens et al., 2022, P., 2). Therefore, it is crucial to set up a **direct relationship between** not only **transparency** and **traceability** but also **sustainability**. Developing and incentivizing strategies that encompass these goals should be a priority in order to achieve a **truly fair and effective transition** towards the circular economy by the industry (Riemens et al., 2022).

To achieve a **holistic transformation**, the participation of **technology, innovation, and proper organization is crucial**. These are key components in developing better strategies and tools for the industry. The relationship between transparency and traceability is not only evident in Riemens et al.'s work, but also in other documents such as the Guidelines for Social Life Cycle Assessment of Products and Organizations 2020 by UNEP, where their relevance in social life cycle analysis is emphasized. The OECD Due Diligence Guidance for Responsible Supply Chains in the Garment and Footwear Sector also highlights **the role of transparency beyond Tier 2** and emphasizes its importance as a collaborative tool. Additionally, it is important to recognize that **transparency has a cost, which companies must take into account** (OECD Due Diligence Guidance for Responsible Supply Chains in the Garment and Footwear Sector, 2018; Riemens et al., 2022; UNEP, 2020).

## *5.3 Case study: Kering's Environment Profit & Loss (EP&L) account*

Next, a case study will be developed on the application of LCA by a fashion conglomerate in the broader context of the Environmental Profit & Loss (EP&L) account methodology. To understand its importance, it is necessary to provide some context and discuss who Kering is as a company, and its significance within the world of fashion sustainability. Additionally, its participation in the field of life cycle assessment will be examined from an aligned perspective.

[30] "Ability to trace the history, application, location or source(s) of a material or product throughout the supply chain (3.2.1)" ISO 22095:2020 (en) Chain of custody-General terminology and models. (ISO, n.d.).

### 5.3.1 General analysis

**Kering**, originally named **Pinault Group**, was founded in 1963 by **François Pinault**. Initially, the company's business model was focused on specialized wood trade. Although much of their empire is mainly related to luxury, they have a diverse portfolio of businesses that have their own specializations. Some of the notable brands that Kering owns include Gucci (The Gucci group), Yves Saint Laurent, Bottega Veneta, Balenciaga, and Alexander McQueen, among others (García, 2013).

One of the characteristics that sets Kering apart from other luxury conglomerates within the fashion industry (despite also having interests in other sectors) is its focus on **sustainability as a core principle integrated into their business model**. This commitment is showed by their inclusion in reports such as the **Dow Jones Sustainability Index (DJSI)**[31], where they have consistently ranked among the top 10% of the best performers in the Consumer Durables & Apparel category in both the global and European indexes since 2014. In addition, Kering has pioneered a novel approach to sustainability through its **Environmental Profit & Loss (EP&L) account methodology**, which aligns its strategy with respect to sustainability (Karski, 2015; S&P Global Switzerland SA, 2022b, 2022a).

### 5.3.2 Environment Profit & Loss (EP&L) account Methodology

Kering is a group that distinguishes itself from its competitors by being particularly mindful of the relationship between the business's impacts, its economic model, and the opportunities and risks this can entail. Moreover, they have been at the forefront of developing a methodology **that assigns economic values to metrics of various factors** that are directly associated with the environment but undoubtedly have a social impact (Kering, 2014, 2022b, 2022a).

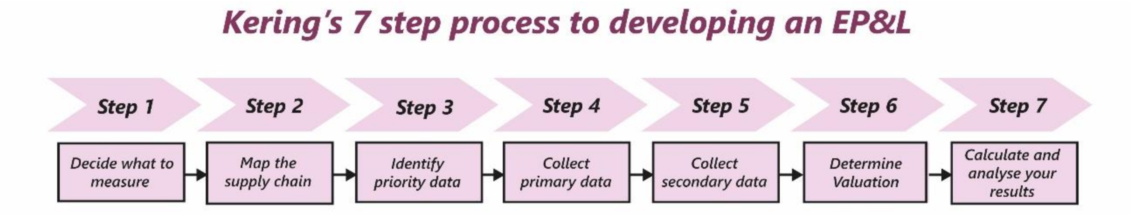
The (EP&L) account methodology was first developed in 2011 by the **Puma brand** as a pilot program, which demonstrated the relevance and opportunities of having such information about the impacts of the business model and supply chain. Kering **recognized the potential** of this pilot and **expanded the program to the entire company group** with the support of consultants and experts from various fields. The resulting methodological framework became **one of Kering's best tools in its sustainability journey** (Kering, 2014).

As the group itself points out in one of its reports "*An Environmental Profit and Loss (EP&L) account is a business management tool providing an in-depth analysis of the resulting impacts a company's activities have on the environment, which also helps decision makers consider this valuable information alongside traditional financial metrics. Kering's pioneering EP&L measures and values in economic terms the environmental impacts across our own operations and entire supply chain*" (Kering, 2022a, p. 2).

It is important to note that the EP&L account methodology consists of **7 interconnected steps**, as shown in the scheme below (Figure 17). These steps are **highly interdependent**, meaning that any changes made to one step will likely affect the others (Kering, 2014).

[31] "The DJSI World & Europe tracks the best-in-class sustainability performers among the 2,500 largest companies in the Dow Jones Global Total Stock Market Index. Applicant companies are rated against an industry-specific questionnaire which covers economic, environmental and social dimensions. Compiled by RobecoSAM, only the top 10% of leading performers in terms of sustainability assessed against these predefined criteria are listed in the DJSI"(Karski, 2015, p. 1,2).

*Figure 17. Kering´s 7 step process to developing an EP&L account.*




Source: adapted from Kering, 2014 (2014).

It is also important to mention that this methodology is supported in turn by different methods, which have a proven **scientific basis** (like LCA) and that enable their own methodology as a useful and practical tool, especially relevant in internal decision making. This is why these methods must follow a strict list of 7 principles: completeness[32], consistency[33], transparency[34], best available approaches[35], location specific[36], data confidence[37] and reflection of impacts on people[38]. The following tools are included among the methods used:

- **Life Cycle Assessment**
- Material flow analysis
- Input-output (IO) tables
- Productivity modeling
- Bespoke analysis

Within the methodology itself, the high involvement of the group to acquire information can also be observed. They analyze **not only primary but also secondary information**. It is important to emphasize that this information is not limited to the first or second level tier, as can be seen in the following image (Figure 18); rather, they go further and try to obtain information **up to tier 4**, where the entities and suppliers responsible for **producing the raw materials** are presumed to be located: *"We collected primary data throughout the whole supply chain, including at raw material production sites in Tier 4"* (Kering, 2014, p. 8).

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[32] "Methods should allow us to capture at least 95% of impacts by value. Completeness should be maintained at each level of the results where they are used to drive decision making. 95% completeness at the top level does not necessarily allow comparability at a lower level of granularity, such as comparing impacts of different materials. It is therefore essential that the completeness criterion is met at each decision level in the results" (Kering, 2014, p. 5).

[33] "Common assumptions across different data sources and methods in the results should be consistent. For example, the same discount rate should be used"(Kering, 2014, p. 5).

[34] "From each data input we should be able to verify data sources and methods used, enabling scrutiny and re-performance. This is important to ensure consistency across third party data inputs"(Kering, 2014, p. 5).

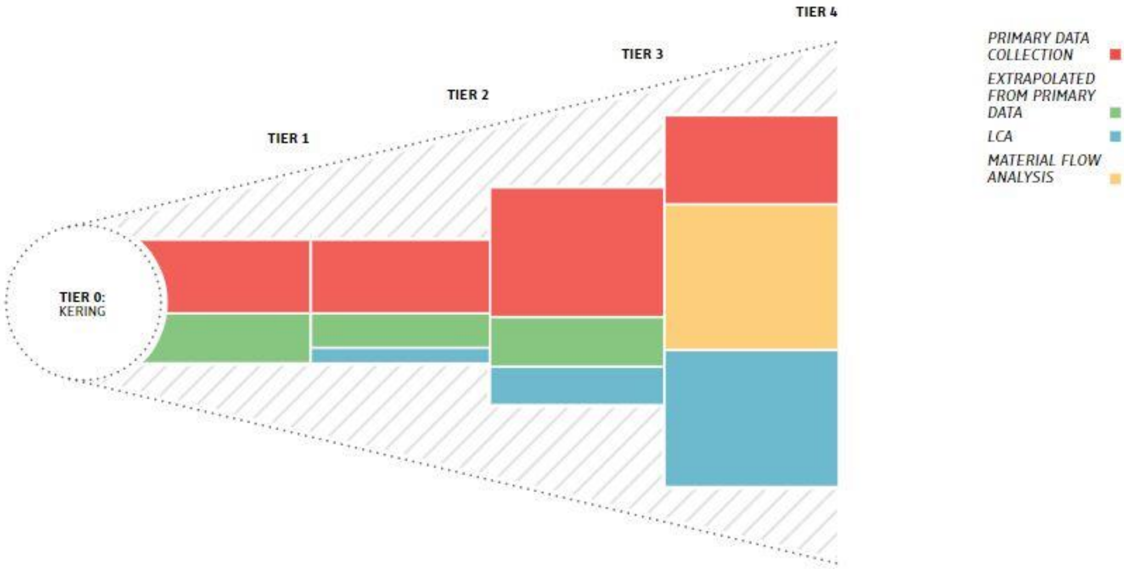
[35] "Wherever practical, the data inputs and approaches used should be the best available to represent each specific impact or process. This includes using primary data wherever possible, and peer reviewed secondary data and estimation methods elsewhere"(Kering, 2014, p. 5).

[36] "All data must be specific to a location to allow the context of impacts to be taken into account."(Kering, 2014, p. 5).

[37] "All data points should have a data confidence rating based on inputs, calculations and assumptions to ensure transparency for decision makers"(Kering, 2014, p. 5).

[38] "The data should allow estimation of the impacts on people in terms of changes of welfare"(Kering, 2014, p. 5).

*Figure 18. Data map of Kering 2013 EP&L (NOT TO SCALE).*




Source: Kering, 2014, P. 8 (2014).

Kering collects the information as shown in the table below (table 5).

*Table 5. Data type collection by Kering group.*

| Data type | From |
|---|---|
| Primary | Kering and its brands |
| Primary | Supplier surveys |
| Secondary | LCA's, national and industry statistics |
| Secondary | Material flow analysis |
| Secondary | Economic models |

Source: adapted from Kering, 2014 (2014).

Thanks to the development of this methodology and its sustainability strategy, the group has been able to make good progress compared to its competitors and other luxury brands. Additionally, they were **the first group within the luxury industry** to prove a **set of standards** and requirements that must be followed by both the group and its suppliers. These standards guarantee specific improvements in areas such as social impacts, traceability, chemical use, environmental impacts, and animal welfare (Kering, 2022a, 2022b, 2022c).

It is also important to understand that the **quantification** of emissions, products, and impacts is a **benefit for the group**. This allows them to develop **proper repair, mitigation, or compensation strategies** based on the results obtained and the **progress seen over the years**.

Regarding quantifiable data and quoting the group, "*Looking at our impact across our value chain, we can see that the impacts related to our direct operations (Tier 0 –stores, warehouses, offices) are still limited, making up 14% of the total impact. The biggest part of our impacts is related to our supply chain (Tier 1 to 4 assembly, manufacturing, sourcing) representing 79% of our total impacts. The impacts associated with the consumer use phase and end of life for products are quite limited, accounting for 7% of total impacts and almost exclusively concentrated in the product use phase. GHG emissions and land use represent our biggest* *environmental impacts and are respectively responsible for 37% and 31% of our EP&L footprint. In 2021 and in absolute figures, they correspond to 2,381,991 tons of CO2 and 299,673 hectares, driven primarily by leather use*" (Kering, 2022a, p. 5,6).

Finally, it is worth noting that the Kering group **not only** has focused on restructuring its business model, but also has sought to **form alliances and provide assistance**, both to companies in the luxury industry and of other sectors, with the aim of creating **real and measurable change:** "*since the supply chain is difficult to influence as one Group alone, we are collaborating with our peers, and across sectors, to drive positive change. As just two examples, The Fashion Pact and the Watch & Jewellery Initiative 2030 are initiatives we established that are focused on collaborating with peers and scaling innovative models around some of the biggest sustainability challenges in our industry"* (Kering, 2022a, p. 6).

### 5.3.3 Findings and recommendations

It appears that Kering has been one of the first companies to start developing a concept of double materiality, at least in terms of the **reciprocity of impacts**, not only from the company to its stakeholders but also from the stakeholders to the company as well. In this sense, Kering recognized the need to implement a system that **collects and regulates data and indicators** of assorted topics that are important for decision-making. This system lies at the core of their method, which is **closely aligned with Life Cycle Thinking.**

It is important to note that the Kering group recognizes a limitation of the EP&L account methodology, which is its inability to conduct **Cradle-to-Grave (C2G) analysis**; this means that it does not fully consider the impacts associated with the consumer stage of its products. However, it should be mentioned that this does not necessarily indicate that the group is not **collecting such information**.

It is important to note that while the EP&L account methodology **focuses mainly on environmental factors**, social impacts are also briefly considered as effects of various environmental factors. Nevertheless, **there is a limitation in not incorporating a more in-depth social section** into the methodology, which could potentially **overlook growing risks** and **emerging opportunities** for the group. By omitting this section, the group may miss out on developing positive impacts, especially given its **large international presence** and alignment with sustainability. Therefore, incorporating a more comprehensive approach of social factors into the methodology could provide **quantifiable benefits for both the brand and its stakeholders**.

Although they specify that LCA is the preferred method when primary information is not collectible or does not meet their requirements, it is primarily used as secondary information. Given the inherent nature of LCA, it is challenging to find available studies that align with the specific locations needed by the Kering group at any given time. While estimations can be made, they are only valid up to a certain extent and under very specific assumptions. This limitation can pose a long-term risk since, as mentioned throughout this thesis, it is crucial to ensure that the collected information is as accurate and reliable as possible to truly gain a competitive advantage.

# 4. Conclusions

The focus of this work on the "environmental" LCA does not imply that it is more important than other methodologies. It is simply that LCA is the pioneer and therefore the best known for now, making it more controlled and studied compared to its counterparts. Despite this fact, each of the methodologies in the LCA family are in constant development for two reasons:

1. In order to properly address the challenges and needs of humanity, which vary based on different criteria, levels, and locations around the world, it is essential to have a range of tools that are specifically tailored to address these different issues.
2. The LCA family is based on scientific criteria and these criteria are continuously updated to provide the best possible response with available information and technology. However, it is important to note that **each method has its own limitations**, all which need to be taken into account and reflected upon. This will enable likely future studies to deepen these limitations and explore new perspectives that were previously not possible to consider.

Furthermore, it is important to recognize that **sustainability is a complex and multi-faceted issue** that requires a comprehensive approach. Therefore, it is necessary to continue conducting research and studies using the **different existing methodologies**. This is particularly clear when considering both scientific articles and case studies, which highlight the **importance of having data to facilitate decision-making and develop effective sustainable strategies**, including areas such as mitigation, repair, or compensation. Advancing in some of the pillars of sustainability, which have an **interdependent character**, is expected to have a positive impact on the remaining pillars. Thus, the use of different methodologies can contribute to a more **holistic and multidisciplinary vision of sustainability**, leading to more effective solutions and a better understanding of the challenges and opportunities that lie ahead.

One of the challenges that deserves highlighting is the **need to comprehend the recycling process of materials and its potential impact on the fashion industry**. This is an intricate and comprehensive topic, which has been dedicated a specific section in this study. It is crucial that consumers grasp that simply disposing of a garment in a recycling container **does not guarantee its 100% effective recycling**. As mentioned, recycling is **inherently complex and demanding**, where even minor modifications to a material's composition can alter **the entire recycling process** necessary to optimally use the resources it offers.

Undeniably, the fashion industry must transition towards a more sustainable model by **embracing circular economy principles** and promoting **eco-design criteria**. This requires a shift in the industry's mindset, moving beyond the traditional focus on short-term trends and aesthetics, and towards creating practical, high-quality products that help multiple consumers without compromising on their properties and appearance. It is crucial to **increase awareness among consumers** about the importance of circularity and the impact of their choices on the environment. By doing so, industry can move towards a more sustainable future and create a positive impact on the planet and society as a whole.

The fashion industry's complexity and fragmentation, as repeatedly explained in this document, are once again highlighted as major challenges. The **low level of transparency throughout the entire supply chain** creates a barrier to achieving proper traceability, as each link is heavily dependent on the others. Given the **linguistic and terminological complexity** within each link and **tier level** of the chain, achieving realistic and efficient traceability is **unlikely** without true, quantifiable, and reliable data, and without a stable general framework that eases the development of standardized information. This creates information gaps that can perpetuate potential risks in the future.

Regarding the limitations, it is a priority to pay special attention to the **functional unit, goal, and scope**, as well as to the entire system behind data collection (primary and secondary). This will enable that LCA studies offer relevant conclusions and appropriately account for bias criteria (cut-off criteria), which can substantially modify a study.

Additionally, while there are highly relevant and enlightening sources available in the literature, the **lack of comprehensive bibliographic material** accentuates the necessity for the fashion industry to conduct more thorough research on crucial and pressing issues such as life cycle assessment in each of its methodologies **beyond the environmental realm**. These studies should be **publicly accessible** as we face a challenge at the sectoral rather than individual level, where **best practices can serve as a catalyst for others** to adopt much more sustainable and resilient practices. The fashion industry urgently needs **synergies and alliances**, both within and beyond the sector, to achieve its goals.

Finally, the analysis of the Kering group's case study proves the **importance of using tools such as life cycle assessment** through its EP&L account methodology to **optimize business decision making**. It is clear that LCA tool should be considered by the industry beyond offering data and estimates. In combination with other methods, it can offer a more holistic view of the impacts resulting from different economic models, which have a reciprocal ability as shown by double materiality analyses. Consequently, it can play a **significant role in making decisions and designing strategies in favor of sustainability.** Furthermore, it is important to mention that beyond providing a superficial explanation of how the LCA tool is used, its methodology (at least the publicly accessible one) does not reveal the extent to which they leverage the benefits of LCA, other than mentioning it as an integral part of the EP&L account methodology.

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