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Applying Design for Environment to a new product to reduce the impact upon the environment

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Finally, I would like to thank my tutor and director of the Master Final Thesis Anna Solans Filella, who has been able to resolve the doubts that aroused me during the process and to help me to find information and articles of interest and guided me throughout the project with regular meetings.

ABSTRACT

This project focuses on the design of a field hockey stick based on reducing the impact upon the environment mindset. In this way, at the beginning of the work, this sport and the material needed to practice it is presented.

The development of products that respect the environment is one of the main goals currently in companies and that's because day after day more people are aware of the problem that we have been causing for many years to our planet environmentally and now that must begin to change radically.

A company have eco-efficient products or services when it can offer that products or services at a competitive price in such a way that it satisfies human needs, increase the quality of their life and reduce the environmental impact of its products or services. So, the design and production of products that respect the environment is the key for companies.

The most used methodologies to design products that respect the environment are Design for Environment and Life Cycle Assessment. By integrating DFE mindset into the design and development process, companies achieve to create eco-innovative and eco-responsible products and services. Besides, Life Cycle thinking is closely related to DFE methodology as they share values and objectives.

Regarding DFE methodology, the step-by-step approach is to design a product that meets requirements for quality, cost, manufacturability and consumer appeal, while at the same time minimizing environmental impacts. On the other hand, Life Cycle Assessment is a standard quantitative tool defined by the ISO 14040 series for analysing the environmental impacts of a product during all stages of its life cycle.

These are the reasons why I will use these two methodologies during this project to design that new product, Design for Environment and Life Cycle Assessment and in one of the following sections they will be depth defined, more specifically in the theoretical content section.

RESUM

Aquest projecte es centra en el disseny d'un stick d'hoquei herba basat en la mentalitat de reduir l'impacte mediambiental. D'aquesta manera, a l'inici del treball es presenta aquest esport i el material necessari per practicar-lo.

El desenvolupament de productes respectuosos amb el medi ambient és un dels principals objectius actualment a les empreses i això és perquè dia rere dia més persones són conscients del problema que fa molts anys que estem causant al nostre planeta mediambientalment i que això ha de començar a canviar radicalment.

Una empresa disposa de productes o serveis eco eficients quan pot oferir aquests productes o serveis a un preu competitiu de manera que satisfà les necessitats humanes, augmenti la seva qualitat de vida i redueixi l'impacte ambiental d'aquests. Així doncs, el disseny i la producció de productes respectuosos amb el medi ambient és la clau per a les empreses.

Les metodologies més utilitzades per dissenyar productes respectuosos amb el medi ambient són el "Design for Environment" i el "Life Cycle Assessment. Al integrar la mentalitat de DFE en el procés de disseny i desenvolupament, les empreses aconsegueixen crear productes i serveis eco innovadors i eco responsables. A més, el pensament LCA està estretament relacionat amb la metodologia DFE, ja que comparteixen valors i objectius.

Pel que fa a la metodologia DFE, l'enfocament pas a pas és dissenyar un producte que compleixi els requisits de qualitat, cost, viabilitat al ser fabricat i atractiu per al consumidor, alhora que minimitza els impactes ambientals. D'altra banda, l'Avaluació del Cicle de Vida és una eina quantitativa estàndard definida per la sèrie ISO 14040 per analitzar els impactes ambientals d'un producte durant totes les etapes del seu cicle de vida.

Aquests són els motius pels quals utilitzaré aquestes dues metodologies durant aquest projecte per dissenyar aquest nou producte, DFE i LCA i en un dels següents apartats es definiran a fons ambdues metodologies, més concretament en l'apartat de continguts teòrics.

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GLOSSARY

CAA	Clean Air Act
CTSA	Comparative Technology Substitutes Assessments
CWA	Clean Water Act
DFE	Design for Environment
EMPA	Swiss Federal Laboratories for Materials Testing and Research
EPA	Environmental Protection Agency
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LCI	Life Cycle Inventory Analysis
NGO's	Non-Governmental Organizations
PLA	Polylactic Acid
SETAC	Society of Environmental Toxicology and Chemistry

1. INTRODUCTION

In this section there will be a brief introduction to this project, by explaining the purpose of the project, a brief description of the different sections we are going to have on the project and its justification.

1.1 PORPUSE

The purpose of this project is to carry out a study by applying Design for Environment and Life Cycle Assessment to a new product, in this case a field hockey stick. The aim of the project is to design a more sustainable product, which means to design a product reducing its impact upon the environment. At the end of the project, it will be analysed if the designed product is environmentally friendly and a cost study will be done to find out how much it would cost to manufacture the product.

1.2 DESCRIPTION AND GOALS

In this project we find a study of the design and production of a product to achieve a longer and more environmentally friendly service life, more specifically the study is about a field hockey stick.

To carry out this project, the first step will be to explain in a basic way what field hockey is, briefly describing the history of this sport, also explaining its rules since they are more complex than most sports and finally listing the necessary equipment to practice it.

Then the theoretical framework of the project will be found, where the two methodologies used in the work will be defined, which are Design for Environment and Life Cycle Assessment. From both methodologies we will briefly describe their history, explain in what they consist of and finally how they will be applied in this study.

Before starting with the practical part, we will see a section in which we will explain other cases in which sustainable design has been applied in the world of sport.

Finally, the practical part of the project will be carried out, where a field hockey stick will be designed based on the Design for Environment and Life Cycle Assessment. Once done, the improvements will be analysed regarding the impact on the environment of the design and a cost study will be done to see the viability of producing / manufacturing this product.

1.3 JUSTIFICATION

When choosing the topic on which the project will work on, it is important to be motivated to be able to carry it out. In my case, this motivation is double since the two topics discussed in the work are of great interest to me.

On the one hand, it motivates me to be able to develop the design of a sustainable and environmentally friendly product since I am aware of the problem that currently exists on our planet, where we are destroying it at high speed and I believe that as a society we must start acting now, even if it is whit a small contribution. Is important to achieve a cleaner and more sustainable planet as soon as possible and that is the reason why I am motivated to be able to discover the different methodologies and strategies to design a sustainable product.

On the other hand, the fact of designing a field hockey stick, a sport that I have been practicing since I was 5, makes the motivation much bigger. The simple fact that I can design a product that I have been using for so many years and think that I can achieve a sustainable and environmentally friendly design is very interesting. What's more, after spending so many years practicing this sport and playing it at a high level, I have met several owners of different field hockey brands that at some point or another in my career have sponsored me and talking with them about the project itself, they have all shown a lot of interest in the subject as they believe that in a short term time, implementing techniques to manufacture sustainable and eco-friendly field hockey equipment will be key.

2 BACKGROUNDS AND CONTEXT

Currently and for many years now, our planet is in a catastrophic situation and most of the blame lies with human beings, who have been overexploiting the Earth in an excessive way until reaching this situation. The world is now warming faster than at any point in recorded history.

Our environment is constantly changing. However, as our environment changes, so does the need to become increasingly aware of the problems that surround it. With a massive influx of natural disasters, warming and cooling periods, different types of weather patterns and much more, people need to be aware of what types of environmental problems our planet is facing and the risks to human beings and all other forms of life on Earth we are going to have in the future.

Global warming has become an undisputed fact about our current livelihoods, our planet is warming up and we are part of the problem. However, this isn't the only environmental problem that we should be concerned about. Across the world, people are facing a wealth of new and challenging environmental problems every day. Some of them are small and only affect a few ecosystems, but others are drastically changing the landscape of what we already know.

The major current environmental problems in our planet are pollution, soil degradation, global warming, overpopulation, natural resource depletion, generating unsustainable waste, waste disposal, deforestation, loss of biodiversity, climate change, ocean acidification, Ozon layer depletion, acid rain, water pollution, overfishing, urban sprawl, public health issues and genetic engineering among others.

We are in a state of planetary emergency, with environmental problems piling up high around us. Unless we address the various issues prudently and seriously, we are surely doomed for disaster. Current environmental problems also require urgent attention.

Currently, it is very important that society begins to act to change the situation. It is true that different governments and political organizations are putting forward different regulations to reduce the impact on the environment caused by human activities, but even that, it is not enough. We need the whole society to be aware of the situation and start changing the mentality from now on if we don't want to destroy our planet, every act, no matter how small, can help counter the situation we're in and if everyone contributes we can reverse the situation.

This is the reason why I decided to carry out this project, it probably won't change anything about the current situation but I hope to create interest on the subject, even if it's just to one other person in the whole world.

3 METHODOLOGY

The design methodologies that will be used in this project to design a field hockey stick reducing the impact upon the environment are Design for Environment and Life Cycle Assessment. Before starting with the project itself, it will be presented what a field hockey stick is, so a brief explanation of the sport and the different equipment needed to practice it must be made.

Once we start working on the project itself, what we must do is to define the two methodologies that will be used. By integrating the DFE mindset into the design and development process, we are going to achieve to create an eco-innovative and eco-responsible product. The DFE approach is to design a product that meets requirements for quality, cost, manufacturability and consumer appeal, while at the same time minimizing environmental impacts.

Besides, Life Cycle thinking is closely related to DFE methodology as they share values and objectives. Life Cycle Assessment (LCA) is a standard quantitative tool defined by the ISO 14040 series for analysing the environmental impacts of a product during all stages of its life cycle.

In the practical part of the project, it will be carried out the design of a field hockey stick based on the Design for Environment and Life Cycle Assessment. In the first stages, when designing the stick, we will focus on the five aspects that the Design for Environment includes that affect to the complete life cycle of the product, which are:

- Materials extraction
- Production
- Transport, distribution and packaging
- Use
- End of life, design for disassembly and design for recycling

Once the stick has been designed, its impact on the environment will be analysed through the Life Cycle Assessment, which we will divide in four different parts that are:

- Goal definition and scoping
- Inventory analysis
- Impact assessment
- Interpretation

Finally, a cost study will be carried out to see the viability of manufacturing this design of the field hockey stick and then, to be able to write the different conclusions that can be extract from the project, especially if the project's objective has been fulfilled or not.

4 PRODUCTS: FIELD HOCKEY STICK

In this section I will explain what a field hockey stick is at it is product to which I will apply the Design for Environment mentality and Life Cycle Assessment strategy during this project to reduce its impact on the environment and extend its life cycle.

First, we will learn about field hockey, what it is, a summary of field hockey history and which equipment is needed to practice it. After that, we will discover the different field hockey sticks brands there are and then decide which brand of sticks to study during the project after doing a benchmarking of them.

4.1 WHAT IS FIELD HOCKEY?

Field hockey is an outdoor Olympic sport played by two opposing teams of eleven players each, ten field players who uses a curved field hockey stick and a goalkeeper, who's equipment is different from field players due to the objective of the sport to hit a small and hard ball into the opponent's goal. It is called field hockey to distinguish it from a similar sport called ice hockey.

Pitch

This sport is played on an artificial grass field which measures 91'40 meters long and 55 meters wide and is divided into two halves. As in most sports, the short lines that delimit the field of play (and on which the goal posts are located) are called end lines. The longest are the lateral lines. In addition to the boundary lines and the central line, there is one more line in each half of the field. It is located 22.9 meters from the end line and is known as the 23-meter line and the part of the field between this line and the end line is usually called the 23-meter zone. Finally, on each side of the field there is an area in the form of a semicircle that surrounds the goal and as we will see in the field hockey regulations, it is the most decisive zone of the field.

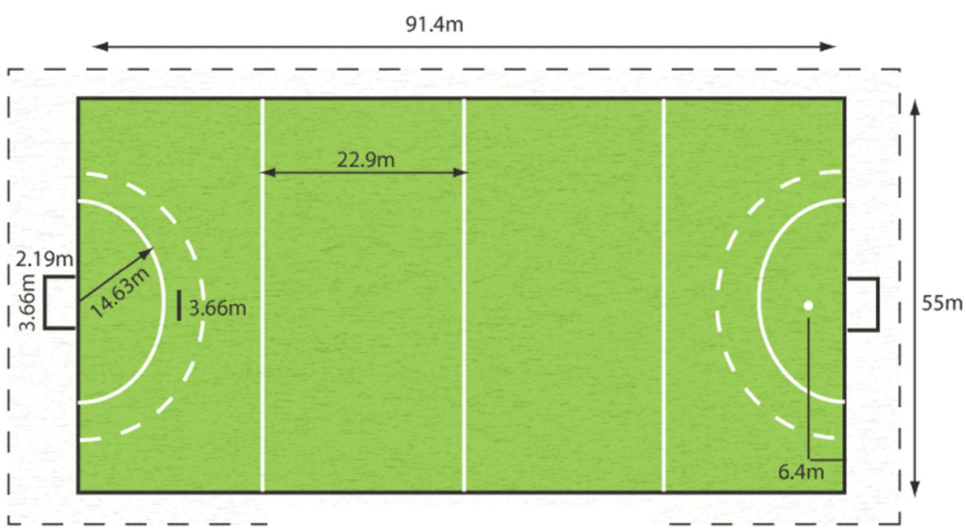

Figure 3: Field Hockey pitch size (Source: ahockeyworld, 2016)

Game playing time

A field hockey match is composed of four periods of 17 minutes and 30 seconds with a break of 2 minutes between the first to second and third to fourth quarter. Between the second and third quarter, at the half of the match, there is a 15 minute break. However, international competitions use a format of 15 minutes quarters. The difference is that in international games the time is stopped during penalty kicks, video reviews and any other situation that significantly stops the game. In general, it is allowed for a match to end with a tied score. However, in competitions where the elimination of one of the teams is necessary, the tie breaker is produced by shoot-outs.

Referees

A field hockey game has 2 referees who control the game and oversee the application of the regulations. They are usually supported, outside the field, by a referee who oversees the time and scored goals.

In high-level competitions (World Cups, Olympic Games, etc.) the figure of video referees also appears. These are in a room where they can review the images of any controversial play. They communicate with the field referees via radio. When this video arbitration exists, each coach has a claim throughout the match. In case they give you the reason, you keep it and you can ask for a review again. It can only be used on specific plays such as goal awarding, penalty stroke, penalty corner and inside the 23-meter zone.

Figure 2: Hockey referee penalizing with green card (Source: FIH, 2023)

Sanctions

Most fouls during a field hockey game are minor and result in a loss of possession. However, there are situations in which this is not enough and in addition to a punishment in the game, it can bring a sanction for the player that has made the foul. All sanctions mean that the team plays with one less member during the time they last, including expulsion for the rest of the game.

There are the three different sanctions that exist:

- In minor offences, the player may be penalized with a green triangular card which implies a 2-minute suspension.

- If there is reiteration or the fault that occurs is more severe, the sanction is marked with a yellow rectangle card that can go from 5 to 10 minutes suspension depending on the referees' decision.

- In serious situations, the suspension can be permanent, forcing the player to leave the field and its surroundings. This type of punishment is indicated by a round red card.

Regulation

The rules of this sport make it unique and special, making it one of the most entertaining sports to watch but at the same time more difficult for the spectator who has never played to understand some fouls. In addition, some rules are constantly changing to encourage the dynamism of the game. Below there is a list of the main rules:

- Field players can only touch the ball with the flat side of the stick. In case of touching it with the opposite side or with any part of the body, it is a foul.

- A common way to trigger an attacking foul is for the ball to be lifted to a height above an opponent's knee and dangerous for any opponent, therefore passing close to or touching an opponent.

- Goalkeepers can touch the ball with all parts of their body within their own area, which is why they are protected with a different equipment than the rest of the players. Outside the area they can only touch the ball with the flat part of the stick, just like the field players and they cannot go beyond the 23-meter zone of the field.

- Normal fouls are taken by stopping the ball and can be taken off by passing to a teammate or driving the ball. Of course, all the players around the foul must be at a minimum distance of 5 meters from where it is committed.

- Most of the fouls are executed normally, although those made in the opponent's area which are punished with a penalty corner, a special type of foul that will be explained now.

During a field hockey match, several plays take place that have their own characteristics. These are:

- Side kick: It occurs when the ball completely crosses one of the side lines of the field. The team that did not touch it last executes this serve from the point where the ball left the court.

- Baseline kick: When an attacker throws the ball out across the baseline, play is restarted with a free-throw for the defending team. It is executed from a point 15 meters from the end line and in front of the point where the ball came out. If it is a defender or the goalkeeper who sends it out, then the game is restarted with a free kick from the 23-meter line. The ball must be placed the spot from which it came out.

- Penalty stroke: It is the maximum penalty that can be applied in field hockey. It is used to penalize 2 types of fouls by a defender in the area. One intentional on an opponent with possession of the ball and another that prevents a foreseeable goal. To execute it, the shooter stands on the penalty spot. On the referee's signal, he shoots the ball, usually lifting it up, to try to get past the goalkeeper.

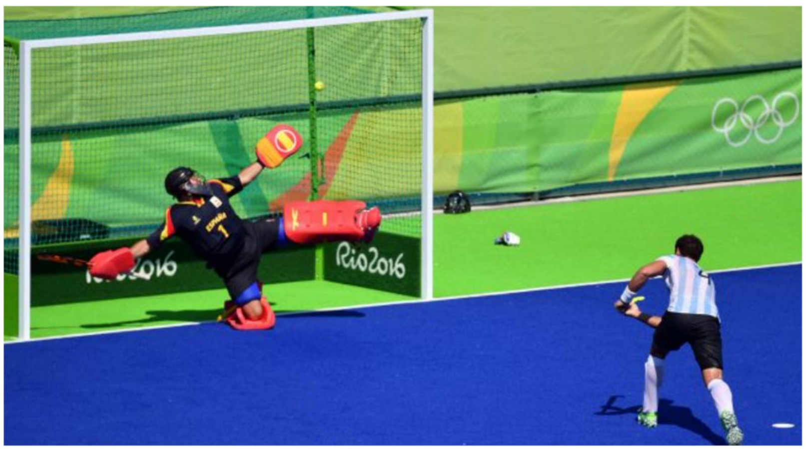

Figure 3: Penalty Stroke (Source: FIH, 2016)

- Penalty Corner: It is also used to penalize fouls by a defender inside the area. One intentional on a rival who does not have the ball and another that does not prevent the probable achievement of a goal. Similarly, it penalizes any intentional foul committed by a defender within the 23-meter zone.

- Free kick: They are awarded for faults committed outside the areas and are executed from the same point where the offense occurred. All players must be at least 5 meters away from that point and the server can choose to pass or play the ball in any direction.

- Shoot Out: It is used just in events that a match ends in a draw and the elimination of one of the teams is necessary. A round of 5 shoot-outs is carried out. Only the goalkeeper and one field player of the opposite team participate in the play and he has 8 seconds to score a goal starting from the 23-meter line. The goalkeeper, for his part, can also get ahead and move around the entire area to avoid the goal.

4.2 FIELD HOCKEY HISTORY

The first graphic representation of two people hitting a ball with long sticks was found in an Egyptian tomb for more than 4,000 years ago. Thanks to the representations that the Egyptians engraved on the walls, we can know that something very similar to hockey was played even then.

The most curious thing is not only that hockey has survived for so long, but that very similar practices took place in very different places and far from each other. Samples of games very similar to hockey have also been found in Persian, Aztec or Chinese culture. Another reference that allows us to follow the trajectory over time is an engraving found on the base of a funerary statue in Kerameikos, a neighbourhood of Athens, dating back to five centuries BC.

Figure 4: Engraving found in Kerameikos (Source: elsuperhincha, 2015)

Whether it was inherited from one culture or another, the truth is that in Europe modern hockey found its base of operations in the United Kingdom and Ireland, where hurling was traditionally played. Hockey began to be played in English schools in the late 19th century, and the first men's hockey club, at Blackheath in south-eastern London, recorded a minute book in 1861. In 1895 international competitions between countries started.

The British army was largely responsible for spreading the game, particularly in India and the Far East. By 1928 hockey had become India's national sport and in the Olympic Games of that year the Indian team, who were competing for the first time, won the gold medal and it was the start of India's domination of the sport which lasted until the emergence of Pakistan in the late 1940s.

The call for more international matches led to the introduction in 1971 of the World Cup. Other major international tournaments include the Asian Cup, Asian Games, European Cup, and Pan-American Games. Men's field hockey was included in the Olympic Games in 1908 and 1920 and then permanently from 1928 until nowadays.

Despite the restrictions on sports for ladies during the Victorian era, hockey became increasingly popular among women and nowadays it is as popular or more than the masculine one. Although women's teams had played regular friendly games since 1895, serious international competition did not begin until the 1970s. The first Women's World Cup was held in 1974, and women's hockey became an Olympic sport in 1980.

The Spanish women's national field hockey team won the gold medal at the 1992 Barcelona Olympic Games after defeating Germany in the final, which is the most important achievement for Spain in field hockey history until nowadays.

Figure 5: Spanish women's national team gold medal 1992 O.G(Source: Mundo Deportivo, 1992)

Currently we find dominant countries from all hemispheres and different zones around the world, which may be because it is a truly universal game. Even so, despite the dominance in the 1970s of the nations with the longest tradition in this sport, such as Pakistan or India, in the modern era those who have dominated international competitions are Australia, the Netherlands, Argentina and to a certain extent, Germany, Belgium and Spain.

4.3 FIELD HOCKEY EQUIPMENT

Field hockey equipment is very complex. In addition, field players and goalkeepers wear different equipment and for that reason in the first section of the Annexes it can be seen each of all hockey equipment accompanied by a brief explanation of their function.

Below you can see an image of a field hockey stick, which is the product to be studied in this project. Although it may seem like a relatively simple component, it is the most important component in the equipment of this sport and that is why this product has been chosen for the study.

Figure 6: Field hockey player stick (Source: Flick Hockey, 2023)

Later and in the practical part, the specific stick model on which to carry out the study will be defined, but for that we must first carry out a benchmarking to analyse the brand to choose.

4.4 BENCHMARKING

Before starting with the theoretical part and talk about Design for Environment and Life Cycle Assessment, which will later be applied in the practical part to a field hockey stick, first we will do a benchmarking of different field hockey brands to know which ones are the most important.

To make this benchmarking, I have selected the most important brands of field hockey in Spain and the factors that will be taken into consideration on that benchmarking to choose the better brand will be the quality of the product and its price.

The brands on which this market study will be carried out are: Osaka, Adidas, Thunder, Ritual, Bravo, Indian Maharadja, TK, Gryphon and Princess.

When assessing how to rank field hockey brands between each other, it is important to know that I have been practicing this sport for nineteen years and during that time I have used at least one stick from each of the brands named below and for assumed, I am able to sort them according to the quality of the product they offer and the average price of these brands.

The market study between the main field hockey brands in Spain will be shown graphically below, where on the X-axis the quality will be evaluated and on the Y-axis the price. The main objective is to visually see which brand will be interesting to analyse on the project, by identifying the market competitors. Below you can see the map:

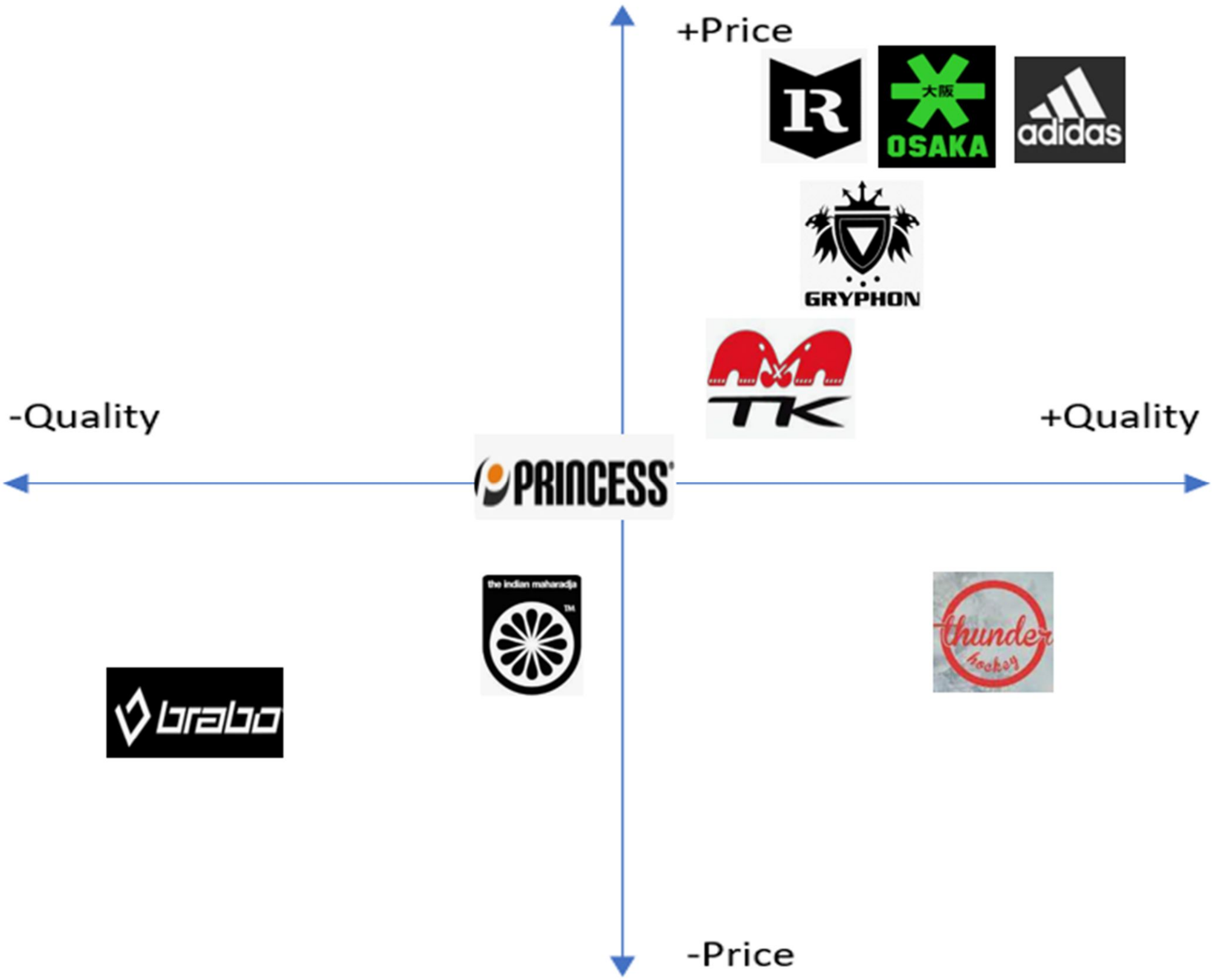

Figure 7: Benchmarking field hockey brands (Source: Own)

As we can see in the image, the brand that is best placed is Thunder as it is in the lower right corner of the benchmarking, offering the highest quality together with other brands but at a much lower price compared to them.

5 THEORICAL CONCEPTS

In this section I will focus on define theoretically both design methodologies that are going to be used to design the field hockey stick and glove, which are Design for Environment and Life Cycle Assessment. I will explain that methodologies that are intended to be applied to the products to make an improved version, at least ecologically speaking.

5.1 DESIGN FOR ENVIRONMENT (DFE)

5.1.1 HISTORY

Beginning of Design for Environment

In the early 1990s, the Design for Environment program began as an innovative and non-regulatory initiative to help companies to consider environmental, human health and economic effects of chemicals and technologies, as well as product performances when designing and manufacturing products and services.

To accomplish the mission of the DFE program, they convened partnerships with NGO's, industry members, academia members and other institutions involved in the project to study and analyse innovative and cost-effective solutions related to human and environmental health for the industry sector.

These partnerships produced several technical resources and analytical documents, which were the CTSA, Best Practices Guidance and Life-Cycle Assessments.

An Emphasis on Safer Chemicals

In the lately 1990s, the DFE program expanded its mission by assessing alternatives the agency priority chemicals and recognizing companies to create better products containing safer chemical ingredients. This expansion was given as a responding to the public's increasing interest in and concerns for the safety of chemicals on common household and commercial products.

Safer Product Labelling Products

In the mid-2000s, the DFE program developed their own certification for safer products and safer chemical criteria based on their standards named "Safer Product Label", allowing companies and consumers to differentiate between their products and the rest of the products of the market, so for the consumers and business purchasers would be easier to identify products that are safer for human health and environment.

DFE Safer Product Label Becomes the Safer Choice Label

In February 2015, the Safer Choice label replaced the DFE product label. The new Safer Choice label has a more modern look to help consumers, businesses and institutional buyers easily recognize products that have earned the label. After the revision, the Safer Choice Label included provisions for the Safer Choice label, an associated fragrance-free label and changes to the standard to implement on it.

Each chemical ingredient of a product has a function in making the product work, whether it is to aid in cleaning, dissolve or suspend materials or reduce water hardness. Within these functional classes, many ingredients share similar toxicological and environmental fate characteristics. As a result, Safer Choice focuses its review of formulation ingredients on the key environmental and human health characteristics of concern within a functional class.

The Safer Choice Program evaluates each ingredient in a formulation against the Master and Functional-Class Criteria documents. These documents define the characteristics and toxicity thresholds for ingredients that are acceptable for Safer Choice products. These criteria documents are based on the EPA expertise in evaluating the physical and toxicological properties of chemicals, and while they incorporate authoritative lists of chemicals of concern, they go far beyond these lists.

Figure 8: Safer choice label (Source: EPA, 2022)

DFE Logo Modernized

In May 2022, the U.S. EPA updated the DFE logo following a surge of engagement from consumers and institutional purchasers wanting to better understand how the products they use affect their health and the environment and to make responsible purchasing choices. The logo modernization aimed to make DFE certified products easier for consumers and purchasers to find and to encourage companies to pursue certification for their products. The DFE logo identifies antimicrobial products, like sanitizers and disinfectants, that meet the health and safety standards of the pesticide registration process under the FIFRA as well as the standards for the DFE program.

Figure 9: DFE modernized logo (Source: EPA, 2022)

5.1.2 DEFINITION

The design for environment (DFE) aim is to reduce the impact that a product or service have to the environment by changing and adapting the design of that product or service. This tool provides a practical method to minimize environmental impacts to create a more sustainable world. The method also maintains or improves product quality and cost while reducing environmental impacts. Although environmental and economic merits are not always compatible, the decisions of the DFE make them so.

There are three characteristics that make this methodology unique, which are the next ones. DFE approach considers all the stages of the life cycle of the product/service, that this means that it isn't only focused on when the product or service is in use, but also before it is used and once its useful life ends, DFE is applied early in the product development process although being in constant improving mentality and last one, decisions are made using principles such as industrial ecology and integrative systems thinking.

Environmental impacts of a product may include energy consumption, natural resource depletion, liquid discharges, gaseous emissions, and solid waste generation. It is during the early stages of the product development process that conscious material use, energy efficiency, and waste avoidance can be specified to minimize or eliminate such environmental impacts. This indicates that if we want to improve the qualities of a product using the DFE, it is essential to do so during the development stage and not once the product is already on the market, since although it is not impossible, the tasks become much more complicated.

The design for environment thinking includes fives aspects to consider while designing that affects to the life cycle of a product and enables companies to be more environmentally friendly in their work. Next, the five aspects will be named, and a small description will be made of the way in which the DFE wants to reduce the environmental impact related to these aspects.

1. Materials extraction:
    - Avoid or reduce the use of toxic, hazardous or materials that in another way are unfriendly with the environment. In this way, future toxic or hazardous emissions will be avoided.
    - Avoid materials with high energy content. Materials like aluminium, needs a lot of energy during their extraction or production, so trying to avoid that materials will mean a reduction of use energy, what will be good for environment.
    - Use renewable, recyclable and recycled materials to reduce the extraction from the earth to get materials and all the processes of extraction of that materials which are environmentally unfriendly.
    - Design products thinking about the reduction of material, by this way big quantities of material will be saved from extraction and being wasted on production.
    - Minimise the number of materials used, to an easier way to recycle the materials from the product.

2. Production:
    - Avoid or reduce the use of toxic, hazardous or materials that in another way are unfriendly with the environment. In this way, future toxic or hazardous emissions will be avoided while production.
    - Reduce and recycle leftover material generated during production processes to increase the life cycle of that materials that otherwise would be wasted.
    - Minimise use of energy intensive process steps, which would represent a big decrease in the amount of energy used during production.
    - Optimize the production installations by having a good distribution and logistics of the production processes. Also, it's important to have prevention and protective measures to avoid health problems from the workers.

3. Transport, distribution and packaging:
    - Use efficient transport by avoiding air transport and lorry, by this way will be a decrease of energy use and emissions from transports, which are environmentally harmful. The best options to transport products being respectful with the environment are train and container ships.
    - Try to avoid long distance transport by working with local suppliers and local products. This will help in reducing emissions and energy from large transport and using environmentally friendly methods of transport.
    - Maximize the efficiency of transportation by using standardized packaging and transport the larger number of products as possible by optimizing the space of the transport and the logistics of the products to reduce the quantity of transportations.
    - Minimise the material used in packaging and the amount of packaging used, by trying to package the products in bigger quantities and trying to use recycled materials for the packaging. By this, it will be a decrease of material used by packaging.

4. Use:
   - Minimise energy consumption during use by using lowest energy consumption components, using default power down mode and insulating heating components.
   - Reduction of the number of consumables used during the use stage by product design, minimising leakage, reusing consumables and use of calibration marks to restrict required amounts of consumables.
   - Optimize lifetime of product by increasing reliability and durability to decrease the need for new products and use of materials and energy from production.
   - Minimise the use of periodical consumables, liquid materials for maintenance and any consumables containing toxic or otherwise hazardous materials.

5. End of life, design for disassembly and design for recycling:
   - Design by possible reuses of the product and not being obsolete after it use to extend the lifetime of the product and decreasing need for new products
   - Design by possible recycling of parts and materials of the products by using recyclable materials, use tables on compatibility of the different materials used, avoid polluting and hazardous materials which are not recyclable, marking any part made from synthetic materials with standardized material codes and minimise painting and fillers.
   - Design by considering safer incinerations of the products by concentrating toxic materials and providing easy removal to decrease environmental unfriendly emissions from incineration process.

5.1.3 PRINCIPLES

The key principles of DFE are:

- Minimizing raw material consumption: DFE encourages designers to minimize the number of raw materials used to create a product. This includes using recyclable or renewable materials, reducing packaging waste and optimizing product size and weight.

- Reducing energy consumption: DFE considers the energy used throughout the product lifecycle and aims to reduce energy consumption through design choices, such as using energy-efficient materials, reducing product weight and optimizing product packaging.

- Minimizing emissions and waste: DFE targets reducing emissions and waste from manufacturing usage and disposal of products. This includes considering the environmental impact of the product's materials, manufacturing processes, packaging and end-of-life disposal.

- Maximizing product lifetime: DFE encourages designers to create products that last longer and require less frequent replacement, reducing the environmental impact of manufacturing, transportation and disposal.

5.1.4 DFE APPLICATION IN THIS PROJECT

The implementation of DFE thinking in any product includes different activities and stages throughout the product life. The first stage begins before the manufacturing process of the product, with the development process of the product design, then with the manufacturing of the product and its useful life and finally with the stage of end of life of the product, what is done with it. Below we will indicate the steps / stages that we will follow during the project to integrate the DFE mentality on it.

1. Select a product and identify its potential environmental impacts/improvements: This step basically consists of selecting the product that will be carried out on the study and analyse which are the possible environmental improvements to implement on it.

2. Set the DFE agenda: This step consists in identifying the internal and external drivers of the DFE, which means to identify the reasons why the project is addressed to analyse and improve the environmental performance of its product. After that, it's also important to define the environmental goals for the product. These goals define how we are going to comply with environmental regulations and how we are going to reduce the environmental impact of the products.

3. Select the DFE guidelines: This step of selecting the DFE guidelines is important to make early environmental decisions without the detailed environmental impact analysis that is only possible after the design is fully specified. In this way we can have a study with environmental improvements before the manufacturing of the product, at which point it will be more difficult to change things. Relevant guidelines should be selected based in part on the qualitative assessment of life cycle impacts of the product studied done in the step 1.

4. Apply DFE guidelines to an initial product design: In this step we are going to apply the relevant DFE guidelines selected in the step 3 to an initial product design. In this way, the initial product design will probably have lower environmental improvements than the final design.

5. Assess the environmental impacts: This step consists in assess the environmental impacts of the product over its entire life cycle, since the first steps until the end of life of the product.

6. Compare the environmental impacts with the DFE goals: In this step we are going to compare the environmental impacts of the first design to the DFE goals established in the step 2.

7. Reflect on the DFE process and results: On this last step, we are going to analyse the results an conclude if the DFE methodology applied in our product has been effective or not in terms of environmental impacts on it.

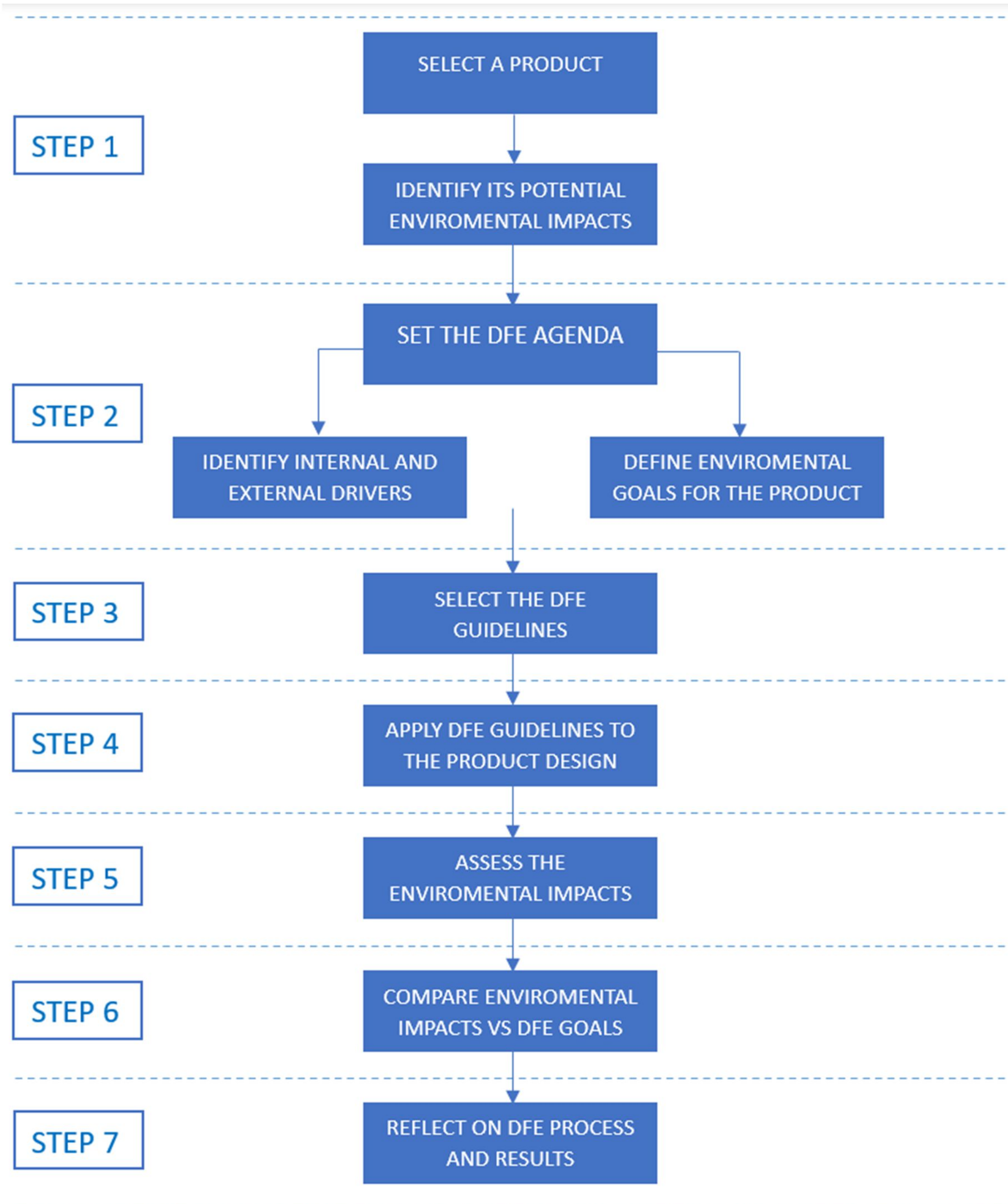

Table 1: Process implementation of DFE (Source: Own)

Once the DFE techniques have been chosen, they will be applied to the product design and when finished, it will be compared with the initial design to see the improvement and if it is not sufficient, the study will be redone.

The factors that will be analysed and improved in each of the steps, which have been seen in the definition of DFE section are: materials extraction, production, transport, distribution and packaging, use and end of life. Below there is an example table of the different points to be studied.

PHASE	DFE GOALS	ENVIROMENTAL IMPACT Q'S	DFE GUIDELINES	POSIBLE SOLUTIONS
MATERIAL EXTRACTION				
PRODUCTION				
TRANSPORT, PRODUCTION AND PACKAGING				
USE				
END OF LIFE, DISASSEMBLY AND RECYCLING				

Table 2: Methodological framework for DFE (Source: Own)

In addition, in the second section of the Annexes named Sustainable Sports Stadia it can be seen a pair of examples of sport projects where DFE methodology have been applied, more specifically to design sport stadiums.

5.2 LIFE CYCLE ASSESSMENT (LCA)

5.2.1 HISTORY

1970-1990: Decades of Conception

The first studies that are now recognized as LCAs date from the late 1960s and early 1970s, a period in which environmental issues became issues of broad public concern. After a period of diminishing public interest in LCA, there has been quickly growing interest in the subject from the early 1980s on. In 1984 the Swiss Federal Laboratories for Materials Testing and Research (EMPA) published a report that presented a comprehensive list of the data needed for LCA studies.

The period 1970−1990 comprised the decades of conception of LCA with widely diverging approaches, terminologies, and results. There was a clear lack of international scientific discussion and exchange platforms for LCA. During the 1970s and the 1980s LCAs were performed using different methods and without a common theoretical framework. LCA was repeatedly applied by firms to substantiate market claims. The obtained results differed greatly, even when the objects of the study were the same, which prevented LCA from becoming a more generally accepted and applied analytical tool.

1990-2000: Decade of Standardization

The 1990s saw a remarkable growth of scientific and coordination activities worldwide, which is reflected in the number LCA guides and handbooks produced.

Through its North American and European branches, the SETAC started playing a leading and coordinating role in bringing LCA practitioners, users, and scientists together to collaborate on the continuous improvement and harmonization of LCA framework, terminology and methodology. Next to SETAC, the International Organization for Standardization has been involved in LCA since 1994. Whereas SETAC working groups focused on development and harmonization of methods, ISO adopted the formal task of standardization of methods and procedures.

In that moment the International Standardisation Organisation (ISO) standardized the following standards.

• UNE-EN ISO 14040: 'Environmental Management. Life Cycle Analysis. Principles and reference framework'.

• UNE-EN ISO 14041: 'Environmental Management. Life Cycle Analysis. Definition of the objective and scope and inventory analysis'.

• UNE-EN ISO 14042: 'Environmental Management. Life Cycle Analysis. Life Cycle Impact Assessment'.

• UNE-EN ISO 14043: 'Environmental Management. Life Cycle Analysis. Life Cycle Interpretation'.

In 2006, all these standards were replaced by two standards, which are the currently two international standards:

• UNE-EN ISO 14040 (2006E): 'Environmental Management. Life Cycle Assessment. Principles and reference framework'.

• UNE-EN ISO 14044 (2006E): 'Environmental Management. Life Cycle Assessment. Requirements and guidelines'.

The Present of LCA: Decade of Elaboration

The first decade of the 21st century has shown an increasing attention to LCA. In 2002, the United Nations Environment Programme (UNEP) and the SETAC founded the Life Cycle Initiative, which main aim was to formulate putting life cycle thinking into practice and improving the supporting tools through better data and indicators.

On 2003, the European Commission underlined the importance of life cycle assessment and the need for promoting the application of life cycle thinking among the stakeholders of IPP. In response, the European Platform on Life Cycle Assessment was established in 2005, mandated to promote the availability, exchange, and use of quality-assured life cycle data, methods, and studies for reliable decision support in EU public policy and in business. In the same year, the U.S. Environmental Protection Agency started promoting the use of LCA.

From this period until today, environmental policy is increasingly based on the life cycle throughout the world and makes more and more companies base their products and businesses on optimizing and improving the life cycle of these, making them more environmentally friendly.

Figure 10: Components of Life Cycle Analysis (Source: Life Cycle Analysis of Biofelus, 2013)

5.2.2 DEFINITION

As I explained before, many tools to guide designers towards making more environmentally friendly decisions in their designs are classified in two categories: Life Cycle Assessment and principles and guidelines for Design for Environment.

Life Cycle Assessment is a standard quantitative tool defined by the ISO 14040 series that evaluate the environmental burdens associated with a product or service by identifying and quantifying the potential environmental impacts related to that product or service and after interpreting properly the results, evaluate the opportunities to affect environmental improvements. LCA evaluates all the phases of the product life cycle, which includes material extraction, processing, manufacturing, fabrication of the product, packaging and distribution of the product, the use of the product by the consumer and the disposal or recovery of the product after its useful life.

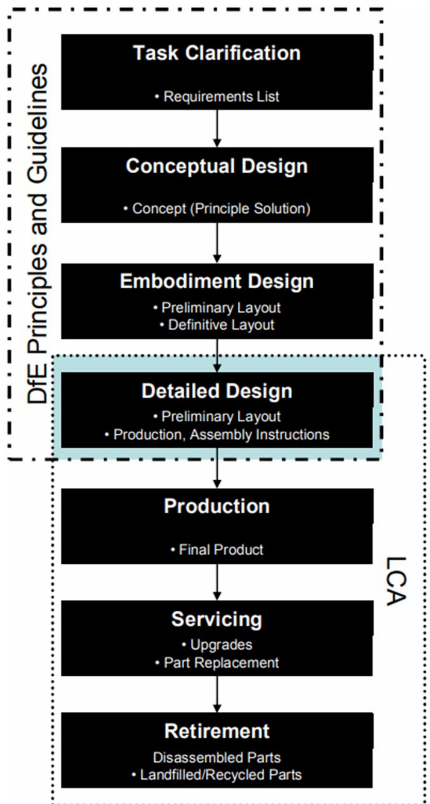

Figure 11: Stages of LCA implementation (Source: Paolo Ciccioni, 2019)

In this photo we can see a product life cycle divided by the stages that make sense to apply DFE on them and which ones we should apply LCA. After seeing the picture, we can conclude that in the first part of the process it is better to use DFE principles and guidelines and once we have the product completely designed it is when LCA starts to being used to analyse the environmental burdens of it.

5.2.3 LEGISTLATION / NORMATIVE

In this section we will briefly define the two standards that in 2006, the International Organization for Standardization (ISO) created to standardize the methods and procedures of Life Cycle Assessment, which still currently being used. These standards are:

UNE-EN ISO 14040 (2006E): 'Environmental Management. Life Cycle Assessment. Principles and reference framework'.

ISO 14040:2006 describes the principles and framework for life cycle assessment including: definition of the goal and scope of the LCA, the life cycle inventory (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements.

ISO 14040:2006 covers life cycle assessment (LCA) studies and life cycle inventory (LCI) studies. It does not describe the LCA technique in detail, nor does it specify methodologies for the individual phases of the LCA.

The intended application of LCA or LCI results is considered during definition of the goal and scope, but the application itself is outside the scope of this International Standard.

UNE-EN ISO 14044 (2006E): 'Environmental Management. Life Cycle Assessment. Requirements and guidelines'.

ISO 14044:2006 specifies requirements and provides guidelines for life cycle assessment (LCA) including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA phases, and conditions for use of value choices and optional elements.

ISO 14044:2006 covers life cycle assessment (LCA) studies and life cycle inventory (LCI) studies.

5.2.4 LCA APPLICATION IN THIS PROJECT

The LCA process is a systematic, phased approach and consists of four components: goal definition and scoping, inventory analysis, impact assessment, and interpretation. In the following picture we can see the general methodological framework for LCA, which is the one that I will use in this project.

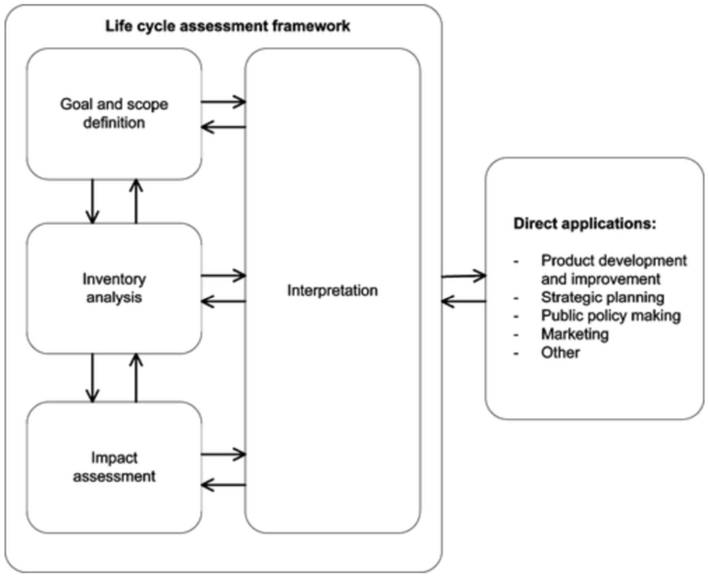

Figure 12: General methodological framework for LCA (Source: American Chemical Society, 2010)

Goal definition and scoping

Define and describe the product, process or activity. Establish the context in which the assessment is to be made and identify the boundaries and environmental effects to be reviewed for the assessment.

Inventory analysis

Identify and quantify energy, water and materials usage and environmental releases (e.g., air emissions, solid waste disposal, wastewater discharges).

Impact assessment

Assess the potential human and ecological effects of energy, water, and material usage and the environmental releases identified in the inventory analysis.

Interpretation

Evaluate the results of the inventory analysis and impact assessment to select the preferred product, process or service with a clear understanding of the uncertainty and the assumptions used to generate the results.

6 PRACTICAL STUDY

Throughout this section a new field hockey stick is going to be designed by applying Design for Environment methodology. Once the product is fully defined, understood and the Design for Environment methodology has been applied, with the aim of analysing its improvements against the impact it has upon de environment we will apply the Life Cycle Assessment.

6.1 FIELD HOCKEY STICK

Before starting with the study of the different stages of the life cycle of the new product, we need to define the field hockey stick to be able to understand the product. There are several parameters of the field hockey sticks that may vary according to the stick model or the chosen brand, that bellow will be defined, which are:

- Size
- Weight
- Stick parts shapes
- Materials

Size

Using the correct stick size is important for good body posture during play. Choosing the correct size can influence the player's technique and is very important to avoid adopting bad habits. The length of a stick varies between 24″ – 35″ for junior hockey sticks and 36,5″, 37,5″ and 38,5″ for senior hockey sticks.

To determine the correct length of the stick I am going to explain the belly button method, which is a well-known and reliable way of estimating the required stick length. For the correct use of the method it is important to take measurements with the field hockey shoes on. Belly button method steps are:

1. Stand up straight.
2. Locate the player's belly button.
3. Measurements:

   a) Option 1: Measure the distance between ground and belly button (more accurate)

   b) Option 2: Measure the height of the field hockey player

4. In the table below, find the correct field hockey player height (column 1) or the correct distance between ground and belly button (column 2).
5. Choose the correct stick size according to the measurements in the table below (if the size is between 2 measurements, the larger one is chosen).

Minimum height adult or child (cm/feet)	Distance between floor and the belly button (cm/ft)	Stick Size
Less than 105 cm / less than 3'44"	< 61 cm / < 2'	Stick size 24"
105 to 110 cm / 3'44" to 3'60"	61 – 68,5 cm / 2' – 2'24"	Stick size 26"
110 to 115 cm / 3'60" to 3'77"	68,5 – 74 cm / 2'24" – 2'42"	Stick size 28"
115 to 120 cm / 3'77" to 3'93"	74 – 79 cm / 2'42" – 2'59"	Stick size 30"
120 to 132,5 cm / 3'93" to 4'34"	79 – 81,5 cm / 2'59" – 2'67"	Stick size 32"
132,5 to 140 cm / 4'34" to 4'59"	81,5 – 84 cm / 2'67" – 2'75"	Stick size 33"
140 to 150 cm / 4'59" to 4'92"	84 – 86,5 cm / 2'75" – 2'83"	Stick size 34"
150 to 160 cm / 4'92" to 5'24"	86,5 – 89 cm / 2'83" – 2'91"	Stick size 35"
More than 160 cm / more than 5'24"	> 89 cm / > 2'91"	Stick size 36,5"
More than 175 cm / more than 5'74"	-	Stick size 37,5"
More than 185 cm / more than 6'06"	-	Stick size 38,5"

Table 3: Belly button method measurements relation (Source: Own)

Weight

The weight of the stick is given in grams since they never reach 1 kg in weight. The advantage of light sticks is that the player can move fast and play easy while otherwise losing some power. Instead, a heavier stick allows to shoot harder but moving it quickly is more difficult. Depending on the playing style and preferences, the choice of stick weight is made. We can divide the sticks according to weight into three categories:

- Superlight (500-525 grams)
- Light (525-550 grams)
- Medium (+550 grams)

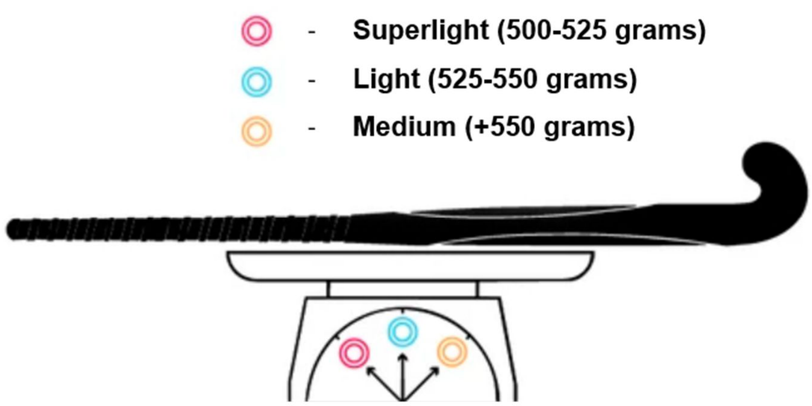

Figure 13: Field hockey stick groups according to weight (Source: Own)

Stick parts

The parts that divide the field hockey stick are:

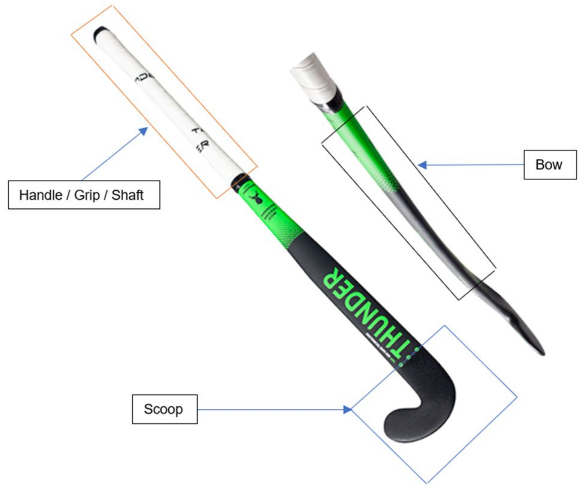

Figure 14: Field hockey stick parts (Source: Own)

Handle / Grip / Shaft: This part of the stick is where players grab the stick. As you can see in the image above players usually place their left hand on top of the grip and their right hand on the bottom of it. The grip area is the only one made with a different material to the rest of the stick. More specifically, in the grip it also reaches the main part of the stick, but since it is the part where the stick is grabbed, this grip is made of a different material to the rest.

Bow: The curve of the stick can vary according to the style of play of each player. The position of the curve is related to where the arc is optimal. This is given in millimetres and gives the distance between the lowest point of the blade to the point of maximum curvature of the stick, the closer the arc is to the ground, the smaller the position value will be. There are three types of bows depending on that distance, which are Mid Bow, Low Bow and Super Low Bow.

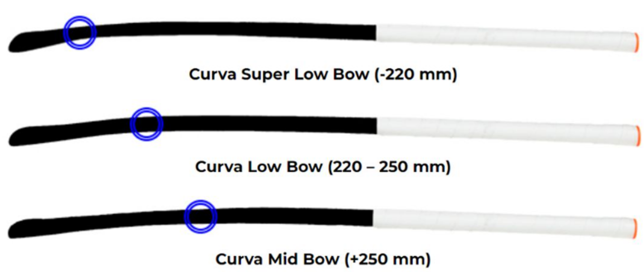

Figure 15: Bow stick types (Source: Flick Hockey, 2023)

Depending on the style of the players, we can define the different bow types as:

- Mid Bow: Traditional player, classic hit, low push.
- Low Bow: 3D dribbling, aerial passes.
- Super Low Bow: 3D dribbling specialist, dragflicks and flicks.

Scoop: The scoop of the field hockey stick is found at the bottom of the stick, the opposite end to the grip. The scoop must be rounded on one side, where the ball can't be touched and flat on the other, where the ball is hit.

The scoop can be subdivided into three different parts, which are the head, the toe and the heel. The head is the part that connects the bow with the scoop, the heel is the bottom of the stick and it connects to the toe, which is the area of the stick that strikes the ball.

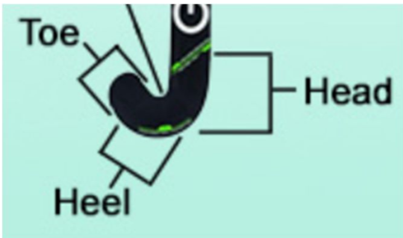

Figure 16: Scoop stick zones (Source: Anthem Sports, 2023)

There are four basic field hockey stick toe shapes, which are Shorti, Midi, J Head and Hook. Toe designs are constructed based on the different ways each position strikes the ball. Here's a brief guide on each toe design.

- Shorti Toe: They are the most common toe design and are primarily used by offensive players. A Shorti Toe allows players to quickly turn the stick over the ball. Shorties also promote control, balance and manoeuvrability.

- Midi Toe: They are approximately a half-inch longer than shorti toes and provide a larger hitting surface for easier ball flicking, receiving and reverse play. Midis are ideal for beginners and midfield players.

- J Head Toe: They combine the extra receiving surface of the hook toe with the hitting power of the midi toe. J Head toe is excellent for drag-flicks and reverse stick control. They are popular with defensive players.

- Hook Toe: They feature a hook design and are made with a two-piece head that provides an extra surface area for increased ball control, better drag-flicks and reverse stick play.

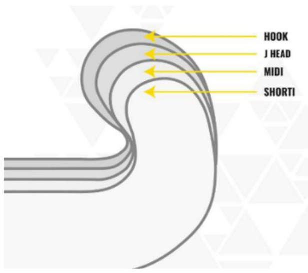

Figure 17: Stick toe shapes (Networldsport, 2018)

Materials

The composition of the hockey stick is important for its stiffness, power and feel in the game. Before, hockey sticks were only made of wood, but currently, apart from continuing to have wooden sticks, although much less, most of the sticks are made of composite, whether they are mostly composed of carbon fiber or fiberglass. So, we can divide hockey sticks according to the materials that are manufactured into two groups, which are:

Composite sticks:

Composite sticks will have different characteristics according to the percentages of the alloy components with which they are made.

Carbon in hockey sticks represent stiffness, power, durability, and strength. The more carbon the stiffer the hockey stick will be. A stiff stick means less flexibility and feel on the ball. Less flex means there isn't a lot of flex in the stick when you hit the ball, this gives the ball more speed when you play. This is one of the reasons why almost all the best players choose clubs with 90-100% carbon. Less feel makes it a bit more difficult to control the ball but for experienced players this is not a problem. Carbon is a very strong but light fiber and that is why the strength and durability of these sticks are very high, but the sticks are still light.

Fiberglass in hockey sticks represent for them to be flexible, affordable, and lightweight. The flexibility of the hockey stick gives less power, but being softer gives more feel and therefore it is easier to control the ball and learn new techniques. The feel of the fiberglass stick is better than carbon sticks but it does not have as much power as carbon sticks have. Fiberglass is also a very light material and it allows for more affordable prices.

Wooden sticks:

Wooden hockey sticks are the most traditional sticks and tend to weight more than composite sticks and they also tend to be less powerful than composite ones but, the feeling you get with wooden sticks is better than with composite sticks, that's why there are still indoor hockey sticks that are still made of high quality treated wood. Also, on the market, wooden sticks are always cheaper than composite sticks.

In addition, the grip of the field hockey stick is the only part of the stick manufactured with a different material than the other parts. For the grip is needed a material with a perfect grip, a pleasant touch and all the precision wanted for the movements since it is the place where the players take the stick. More specifically players place their left hand on top of the grip and their right hand on the bottom of it. For this reason, most grips and overgrips are made of different types of plastic materials.

6.2 THUNDER TH-TRISKELION

When designing the new stick we will have to take as a reference some model that currently exists since although it is true that there is some variety between the different models of sticks that exist and the different brands of hockey on the market, the overall design of the sticks is very similar to each other and we need a stick model to create the stick shape and dimensions.

In this project, after benchmarking the most important field hockey brands in Spain, the Thunder Hockey brand came out as the best positioned in terms of relation between money and quality as we can see in section 4.4. For this reason I contacted Pol Garrido, owner of the Thunder Hockey brand, who I luckily knew because a couple of years ago I had been sponsored by that brand.

After talking with him about my project, I asked him for information about one of his stick models to have a reference base when designing the stick. The truth is that he showed a lot of interest in the subject and without problem sent me the datasheet of one of his stick models, more specifically from the Thunder TH-Triskelion model.

In the following section I will define the Thunder TH-Triskelion parameters (size, weight, stick parts shape and materials), which it will help me to find, for example, materials like those used but which are still more environmentally friendly. In addition, for the new stick design, minus some optimization changes in the design I will take the same shape and dimensions than the Thunder TH-Triskelion, for this reason I will also create a 3D model of that stick.

Size

To choose the size of the Thunder TH-Triskelion stick I will use my own measurements. In this case, my height is 176 cm, so according to the belly button method (table 3) I must choose a size 37.5" stick. In the thunder hockey website, we can see that the 37,5" size for that stick model is available.

Minimum height adult or child (cm/feet)	Distance between floor and the belly button (cm/ft)	Stick Size
More than 160 cm / more than 5'24"	> 89 cm / > 2'91"	Stick size 36,5"
More than 175 cm / more than 5'74"	-	Stick size 37,5"
More than 185 cm / more than 6'06"	-	Stick size 38,5"

Figure 18: Stick size choice by belly button method (Source: Own)

Figure 19: Thunder TH-Triskelion available sizes (Source: Thunder Hockey, 2022)

Weight

The Thunder TH-Triskelion stick weight is 512 grams, for that reason we will classify that stick model as a superlight stick.

TH-Triskelion

Peso: 512 gramos

Figure 20: Thunder TH-Triskelion weight (Source: Thunder Hockey, 2022)

Stick parts

Bow

The Thunder TH-Triskelion has a low bow as the distance between the lowest point of the blade to the point of maximum curvature of the stick is 250mm. For this reason we are going to use that bow in our design.

TH-Triskelion

Curva: Low Bend 25mm (a 25 cm de la pala)

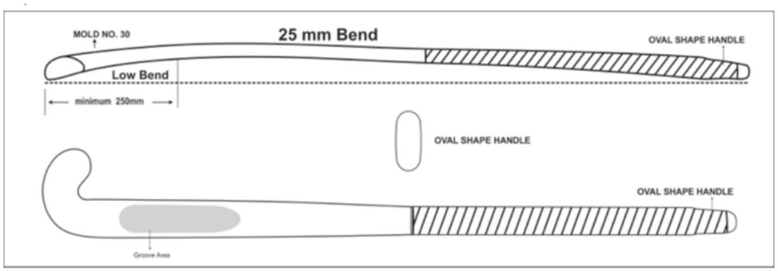

Figure 21: Thunder TH-Triskelion bow (Source: Thunder Hockey, 2022)

Toe

As we can see in the image below, the Thunder TH-Triskelion has a Hook Toe. For this reason we are going to use that toe shape in our design.

Figure 22: Thunder TH-Triskelion toe (Source: Thunder Hockey, 2022)

Materials

The Thunder TH-Triskelion material composition is 92% carbon fiber, 5% Kevlar and 3% fiberglass. In this way, the stick will be rigid, powerful, durable and very resistant.

TH-Triskelion

Material: 92% de carbón + 5% Kevlar + 3% Fiberglass

Figure 23: Thunder TH-Triskelion stick material (Source: Thunder Hockey, 2022)

The Thunder TH-Triskelion grip is made of high-grade Taiwanese polyurethane (PU), a material with great anti-slip properties, perfect for a good grip of the hands on it.

General shape and dimensions

In this section there are several images taken from the Solidworks 3D design software, with which I have designed the Thunder TH-Triskelion stick size 37.5". The reason why I decided to do the 3D design of the model is to take it as a reference and apply possible design optimizations. In addition, to later design a possible packaging for the stick I will also use the same program to do it and I will be able to compare it with the real measurements of the stick after designing it.

In the first image of the section (figure 46) it can be seen the Thunder TH-Triskelion in real life, the photo is from the official Thunder website.

Figure 24: Thunder TH-Triskelion website (Source: Thunder Hockey, 2022)

The figure 47 is an image of the Thunder TH-Triskelion stick designed in 3D. In that image it can be seen the stick itself, without the grip or the adhesive tape.

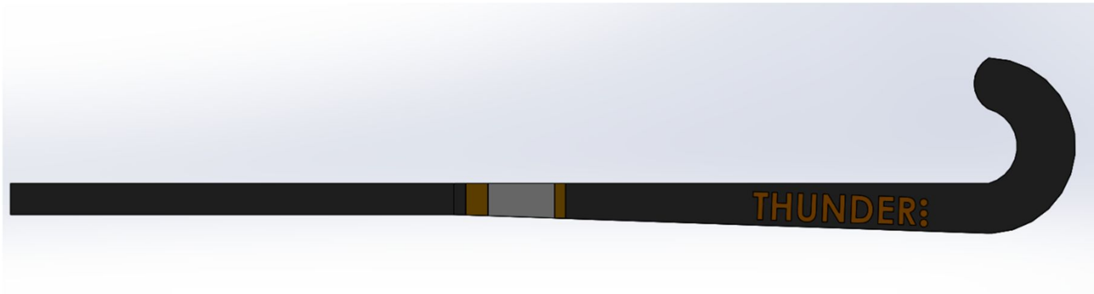

Figure 25: Thunder TH-Triskelion stick 3D CAD (Source: Own)

The figure 48 is an image of the Thunder TH-Triskelion stick designed in 3D, but in this case I added the grip on it by having the stick assembly.

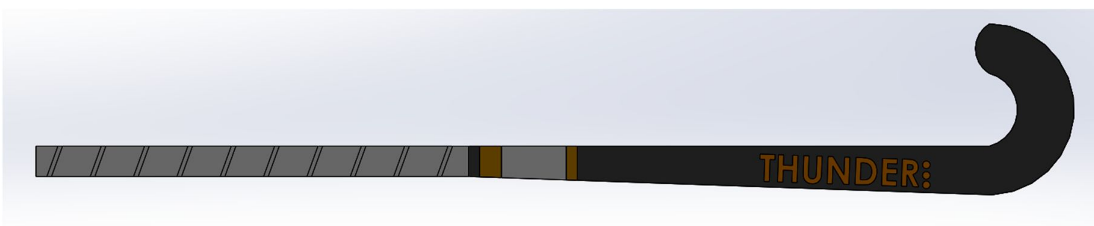

Figure 26: Thunder TH-Triskelion stick assembly 3D CAD (Source: Own)

6.3 APPLYING DESIGN FOR ENVIRONMENT TO THE NEW STICK

The design for environment methodology will be applied to the Thunder TH-Triskelion to design a new stick more responsible and environmentally friendly. Throughout this section, the different sections that make up the methodology will be developed in an extensive and justified manner with the final objective of achieving a product which global life cycle is as ecological and responsible as possible. To distinguish between the Thunder TH-Triskelion design and the new stick design, we will name this second design ECOTHUNDER.

6.3.1 MATERIALS EXTRACTION

In this first stage of the DFE methodology we will analyse the extraction and use of materials. Firstly, the materials used in the Thunder TH-Triskelion will be analysed. The objective is to understand the technical and functional properties of that materials and detect if they are environmentally friendly or not.

In case that the materials used to manufacture the Thunder TH-Triskelion are not respectful with the environment or there are materials with very similar properties and applications that are more respectful with the environment, either when extracting them or in subsequent production processes, these materials will be used in the ECOTHUNDER design.

THUNDER TH-TRISKELION ASSEMBLY – MATERIAL EXTRACTION

ALLOY: 92% CARBON FIBER + 5% KEVLAR + 3% FIBERGLASS

Zone: This alloy is found in the main part of the stick model assembly, as it is the unique material that make up the stick itself.

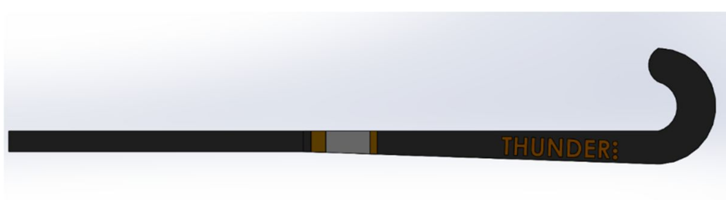

Figure 27: Thunder TH-Triskelion carbon fiber alloy zone (Source: Own)

Properties:

- Carbon fiber: This material provides rigidity, power, durability and strength to the product while it is characterized by being a light material. In this model, 92% of the material is carbon fiber so it is the majority component by far and therefore these characteristics are what will define the stick.

- Kevlar: The best property of Kevlar is its strength and in this way it helps the stick by strengthening it. In addition, it is also a light and comfortable material.

- Fiberglass: This material brings flexibility, affordability and lightness to the stick. In this model, since there is only 3% fiberglass in the stick, these characteristics are not very decisive.

Environment Behaviour:

- Carbon fiber: This material has a complex manufacturing process. To obtain it, it is necessary to invest a large amount of energy and water to subject the precursor polymer to the temperatures necessary to initiate the chemical processes of its manufacturing process. Inevitably, the investment of these two resources, energy and water, contributes to a highly polluting process. In addition, the recycling of this material is very complex and expensive.

- Kevlar: To make Kevlar, sulfuric acid must be used. This process is not good for the environment since sulfuric acid has devastating effects on the environment. Once manufactured it can be considered sustainable as it can be recycled.

- Fiberglass: Due to the products with which it is combined and what it becomes, glass fiber can create a danger for the environment since it does not decompose and is almost impossible to recycle. On the other hand, it decreases the felling of trees and the generation of plastic waste that ends up in surface water bodies and sanitary landfills.

POLYURETHANE (PU)

Zone: This material is found in the grip of the stick model assembly, as it is the unique material that make up the grip.

Figure 28: Thunder TH-Triskelion polyurethane zone (Source: Own)

Properties: The polyurethane is characterized to be an elastic material, with a great anti-slip properties and very resistant to water, oil and grease, apart from its transparency. It is the perfect material for its application since the players can use the stick on rainy days and without suffering from the grease from the sweat of their hands due to the anti-slip properties.

Environment Behaviour: Polyurethane has very low emission levels. In addition, thanks to its excellent durability, it extends the useful life of the material, so it will save more energy and resources. The only important issue in order not to negatively affect the environment is not to leave this material in landfills once its useful life has ended. The most advisable thing is the incineration to produce energy or the recycling of it, giving a second use to the plastic.

ECOTHUNDER ASSEMBLY – MATERIAL EXTRACTION

PLA + FLAX FIBER COMPOSITE

Zone: This composite is found in the main part of the stick model assembly, as it is the unique material that make up the stick itself.

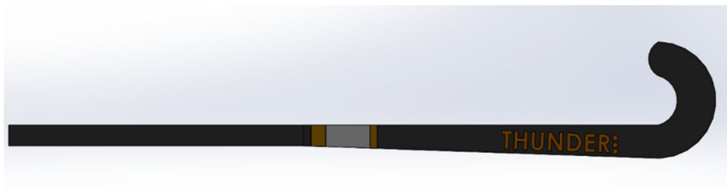

Figure 29: ECOTHUNDER flax fiber composite zone (Source: Own)

Properties:

- Flax Fiber: This material achieves the same rigidity, power, and strength as carbon fiber while meeting the same safety and quality standards and offering savings of considerable weight compared to carbon fiber. In addition, according to the Swiss company Bcomp, which manufactures this material, its manufacture is 30% cheaper and with less energy consumption compared to carbon fiber. In this assembly the stick itself is the most important part, so this material is the major component by far and therefore its characteristics are what will define the stick.

- Polylactic Acid (PLA): It is a resistant, rigid, flexible material, with low flammability, odourless and easy to handle.

Environment Behaviour:

- Flax Fiber: Bcomp claims that using the flax fiber instead of carbon fiber reduces CO2 emissions during manufacturing by 75%. In the manufacturing process of these materials there is no process that requires high temperatures involved. In the field the crop is grown naturally and processing is water based. After the flax is harvested to make any type of fabric, the flax is left to rest in the field for a while to allow the outer surface to break down, making it easier to extract the fibers while also enriching the soil. In addition, the flax fiber is made from a plant that absorbs CO2 from the atmosphere during its growth, it can be incinerated at the end of its life and still be CO2 neutral. That is why it is a sustainable material extracted from natural and renewable resources.

- Polylactic Acid (PLA): It is an environmentally friendly filament since it does not require finite resources such as oil. Its origin is found in raw materials such as corn starch, tapioca roots or sugar cane. From these starches and food, an ecological and renewable plastic is obtained that, under certain conditions of temperature and humidity, can be biodegradable. In addition, using PLA filaments in 3D printing can be interesting for companies looking to change their manufacturing processes to make them more sustainable.

RECYCLED POLYURETHANE (PU)

Zone: This material is found in the grip of the stick model assembly, as it is the unique material that make up the grip.

Figure 30: ECOTHUNDER recycled polyurethane zone (Source: Own)

Properties: Recycled polyurethane allows to have practically the same properties and characteristics than polyurethane by reducing the CO_2 emissions produced during production process of it. So its properties, like polyurethane, are elasticity, non-slip and highly resistant to water, oil and grease.

Environment Behaviour: Polyurethane is 100% recyclable. In fact, waste can be recycled in various ways to give it a new life. The recycled polyurethane allows to save on raw materials, waste, CO_2 emissions and energy costs. In addition, it represents significant economic savings. On the other hand, its great durability, the transport savings that its lightness implies and its good manageability, result in a low carbon footprint throughout its useful life.

6.3.2 PRODUCTION

In this section the production processes of each of the parts necessary to obtain the product Thunder TH-Triskelion model and after that we will carry out an analysis to improve the production processes from the ECOTHUNDER model.

THUNDER TH-TRISKELION ASSEMBLY – PRODUCTION

<u>ALLOY: 92% CARBON FIBER + 5% KEVLAR + 3% FIBERGLASS</u>

Production process:

Most hockey brands (90%), which are many, manufacture their products in Sialkot, Pakistan. The Thunder brand is no exception. Once it is known where the production of the Thunder sticks is located, the manufacturing process of the sticks will be analysed.

The first step consists in designing the 3D model part, the stick is not a very complex product but is important to define its dimensions.

The alloy (92% carbon fiber, 5% Kevlar and 3% fiberglass) sheets are then manufactured. Sheets are made from giant rolls of this alloy. Once the sheet is made on the roll, it is first cut into smaller sheets and then into strips to give the stick a better shape.

Once the strips of material are made, they are joined together to form the shape the hockey stick model.

Before being placed in the mold, it is calibrated that the curvature of the stick is correct and that its weight is within acceptable ranges.

The next step consists of preparing the mold prior to its use.

After this, the final shape to the stick is given, creating the shape of the hook to be able to correctly insert the stick into the mold.

The stick is melted for 20 minutes to then be placed in the mold so that it takes the shape of the mold correctly. Then it's time to inject air into the stick through the wires of the mold.

After the injection of air, the stick is removed from the mold and the imperfections are corrected before proceeding to paint it.

In the painting process, it is necessary to prepare the paint first, then spray it and finally add the final water decal to the stick.

Finally, the sticks are left in the drying area to dry the paint and thus the stick is ready to add the grip.

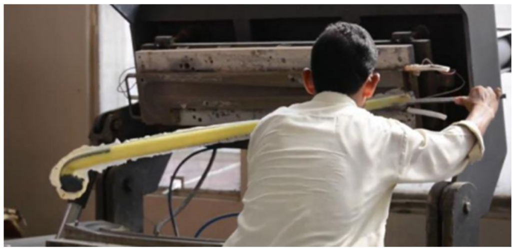

Figure 31: Thunder TH-Triskelion stick production process (Source: Own)

Inputs:

- New carbon fiber, Kevlar and fiberglass particles
- Energy from non-renewable sources
- High emission paints

Outputs:

- Heat from high temperature melting process
- Carbon fiber composite waste
- Harmful gases after the melting process
- Finished stick parts
- Traces of paint
- Toxic substances after the painting process

<u>POLYURETHANE (PU)</u>

Production process:

To obtain the PU strips that form the grip, the production process starts with the melting in an oven of polyol and isocyanate, which are the components that make up the PU.

Then, the liquid mixture is poured into an injection mold, which is shaped like strips, where the air injection is applied to cool and take its shape.

Finally, the part is removed from the injection mold and a visual quality inspection is made.

Once the PU grip is manufactured it is placed circling around the upper part of the stick.

Figure 32: Thunder TH-Triskelion grip production process (Source: Own)

At the end of the production process, the stick is ready to pass the quality test before being packaged.

Inputs:

- New polyurethane particles
- Energy from non-renewable sources

Outputs:

- Heat from high temperature melting process
- Harmful gases after the melting of polyol and isocyanate
- Polyurethane waste
- Finished grip

ECOTHUNDER – PRODUCTION

<u>PLA matrix+ FLAX FIBER COMPOSITE</u>

Production process:

Until recently it was impossible to produce field hockey sticks in 3D printing due to their dimensions and materials, but this technology has increasingly evolved and its manufacture is currently possible both by materials and by dimensions.

To manufacture the ECOTHUNDER stick model, a 3D printer will be used. The combination of PLA's ease of printing with the mechanical properties of flax fibers will create 3D printed parts with good mechanical properties and an organic finish in a simple way. As the material used is a PLA + flax fiber composite, an FDM printer will be used.

FDM 3D printers are based on three elements, a bed or plate where the part is printed, a coil of filament or printing material, and an extruder. The extruder of the FDM 3D printer sucks in the filament and melts it to deposit it layer by layer on the print bed until the final product is finished.

This manufacturing method has economic and sustainable advantages over traditional processes, among the most notable:

- Waste reduction: The 3D printer only uses the material it needs when adding the layers, so the waste it generates is minimal.

- Reduced energy consumption: the manufacturing process is faster, so less energy is consumed. The parts produced by this type of manufacturing are much lighter, which saves operating energy and emits fewer emissions.

- Sustainable material: Biodegradable materials can also be used to manufacture parts. In this case, PLA + flax fiber is used, which is biodegradable and with resistant properties.

Figure 33: FDM 3D Printer CR-1000 Pro (Source: Own)

Inputs:

- Biodegradable PLA + flax fiber filaments

- Energy from non-renewable sources although less energy is consumed than traditional processes

Outputs:

- Heat from printing process

- PLA + flax fiber traces although in very small quantities that are reused in subsequent prints

RECYCLED POLYURETHANE (PU)

Production process:

The manufacturing process of the recycled PU grip uses polyurethane particles that are made from recycled raw materials. Polyurethane is 100% recyclable and its recycling process follows these stages:

- Shredding: It is done with mills or shredders.
- Washing: Plastic impurities are separated and then dried removing humidity.
- Extrusion: A pressing process is carried out molding the polyurethane, which by continuous flow with pressure and thrust causes the PU to melt and then it is passed through a mould to give it the desired shape.

Inputs:

- Reused polyurethane particles
- Energy from renewable sources

Outputs:

- Heat from high temperature melting process
- Pre-filtered gases
- Polyurethane waste that will be recycled
- Finished grip

6.3.3 TRANSPORT, DISTRIBUTION AND PACKAGING

In this section, the transport, distribution and packaging of the ECOTHUNDER stick model will be analysed so that it is as sustainable as possible. To carry out this study we will assume that our workshop will be focused on Catalonia, Spain.

Transport and distribution

The ECOTHUNDER model belongs to the Hockey Thunder brand, which has the store in Terrassa, more specifically in Plaça Doctor Zamenhoff 6.

Figure 34: Thunder Hockey Store Location (Source: Google Maps, 2023)

A big number of field hockey clubs in Catalonia are in Terrassa. In fact, this city is considered the birthplace of field hockey throughout Spain. For this reason, having the store in Terrassa is a good location since it is the city with more field hockey players in Catalonia.

For the manufacture of the sticks I had to look for a parts manufacturing centre with FDM 3D printers. The option I have chosen is WASP HUB Barcelona, a new space specialized in 3D printing service, consulting, design and technical support in the centre of Barcelona, more specifically in Gran Via de les Corts Catalanes 690, Eixample, 08010, Barcelona, Spain.

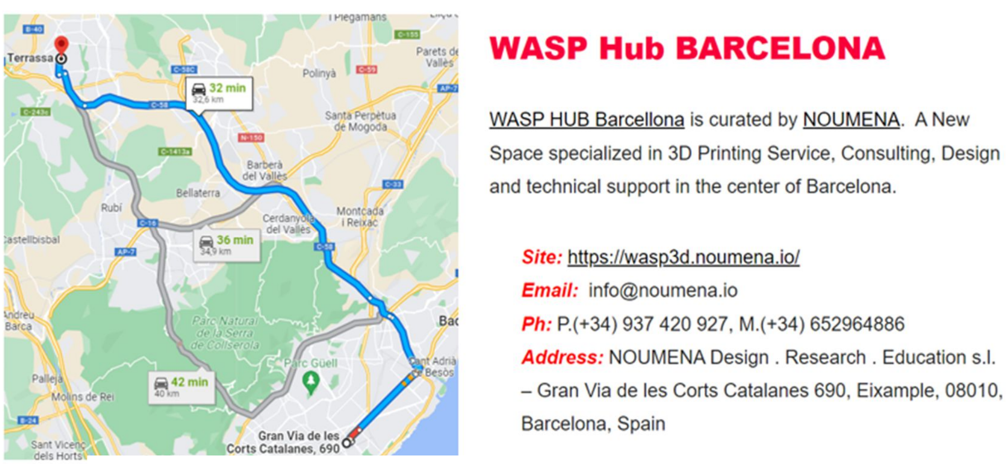

Figure 35: WASP Hub Barcelona Location (Source: Google Maps, 2023)

As we can see in the image above, the WASP HUB Barcelona is 32.6 km by road to the Thunder store so it can be considered a short distance what is crucial to minimise transport. Being a short distance, transport must be by land, that is why we will use an electric truck for transport, this way they also eliminate the combustion gases generated from other vehicles.

On the other hand, to optimize the truck trips from the stick production centre to the store, we will fill the truck to the maximum number of sticks available, by this we will minimize the number of trips.

In the case of the manufacturing process of recycled PU hockey grips, I have decided to do it in a company specialized in the recycled plastics sector called Plásticos Calles located in Castellbisbal, more specifically in Pol.Ind.Comte de Sert, Carrer Motors, 28, 08755 Castellbisbal, Barcelona.

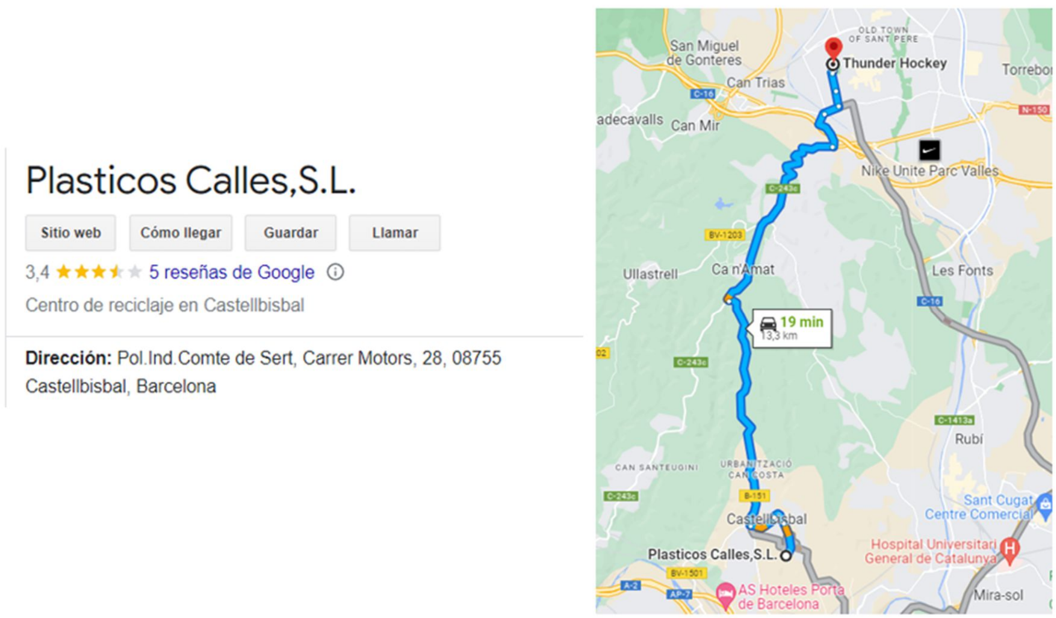

Figure 36: Plasticos Calles S.L. Location (Source: Google Maps, 2023)

As we can see in the image above, Plásticos Calles is 13,3 km by road to the Thunder store so it can be considered a short distance, which means that is even shorter than the other transport so it must be also by an electric truck. In this case we will also optimize the truck trips by filling up the maxim number of grips available in the truck.

Packaging

In this section we will focus on designing the final packaging that will be put on the stick once it has been manufactured and must be sent to the store. First, once manufactured the stick will be packed it using recycled shrink plastic, which will surround the stick until it is completely covered. We will get this recycled shrink plastic from the Vilapack company and we will apply it to the stick using a shrink gun, thus achieving greater protection for the stick against impacts and other environmental factors during transport. In the image bellow we can see the stick after being covered by recycled shrink plastic.

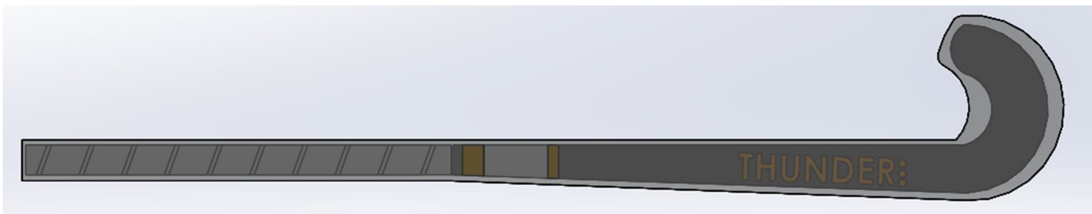

Figure 37: ECOTHUNDER covered by recycled shrink plastic (Source: Own)

Finally, the sticks already packed with recycled shrink plastic will be placed in a 100% cardboard box pallet from the Vilapack company. The fact of choosing the pallet box instead of using conventional cardboard boxes is because the pallet box holds a greater number of sticks, so we will save large amounts of cardboard when packing the sticks. In these packaging systems, resistance is especially important, since they are designed to house a lot of material. This causes them to be subjected to high loads, so the cardboard must be able to withstand high stresses. In addition, since they are made of cardboard, they are 100% recyclable, helping to reduce the environmental impact.

In addition, another advantage of using the cardboard box pallet is that its dimensions coincide with the dimensions of the pallet, which is a standard packaging system that allows storage and transport in a much simpler way. In this specific case, the most restrictive measure of the sticks is the length, which in the case of a 37.5" size stick is 95.25 cm (952.5 mm). That is why with the dimensions of the Europalet that measures 1200 mm long by 800 mm wide is enough to store the sticks inside.

Figure 38: Cardboard box pallet from Vilapack website (Source: Vilapack, 2023)

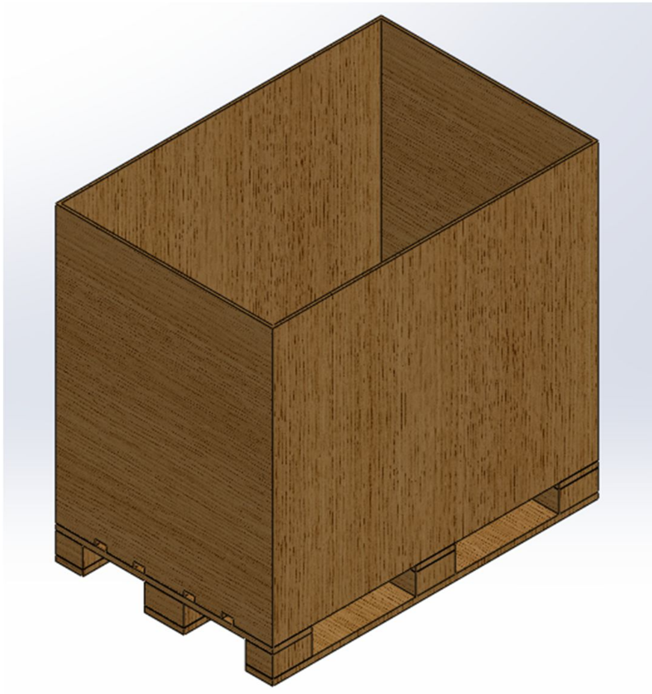

Figure 39: Cardboard box pallet 3D CAD (Source: Own)

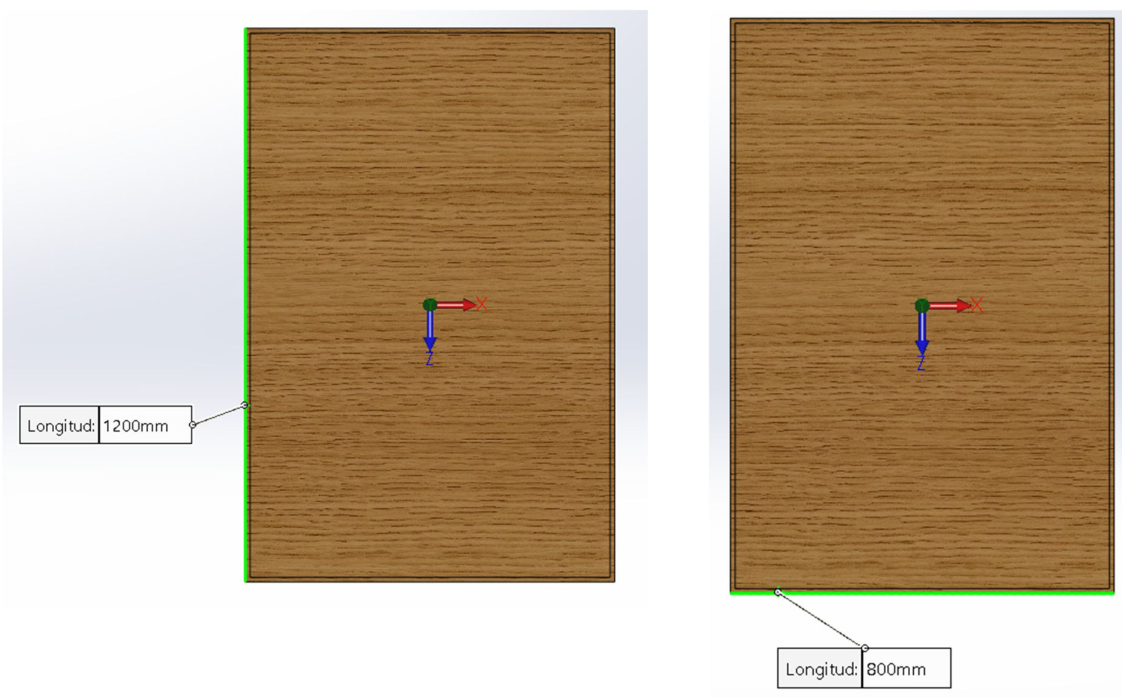

Figure 40: Cardboard box pallet dimensions (Source: Own)

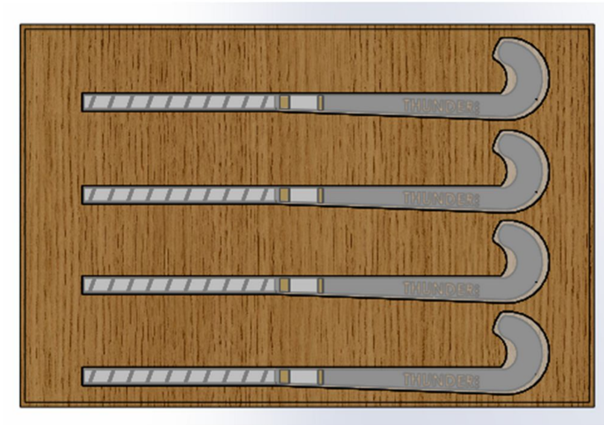

Figure 41: ECOTHUNDER packaging 3D CAD assembly (Source: Own)

As we can see in the image above, in a box pallet with Europalet measurements, up to four rows of sticks fit, so if we stack the sticks up to the height that the box pallet reaches in these four rows, we can place many sticks in and then transport and handle it in a simple way due to the standardization of Europalet measurements.

6.3.4 USE

When studying the environmental impacts of field hockey sticks during its use, I can conclude that there isn't any bad impact upon the environment so in this stage we cannot study any possible change to apply on the ECOTHUNDER.

6.3.5 END OF LIFE, DESIGN FOR DISASSEMBLY AND DESIGN FOR RECYCLING

Finally, we will analyse the end of life, design for disassembly and design for recycling of the ECOTHUNDER, which is the last stage from the Design for Environment procedure. In this section, we will first see the opportunity to extend the useful life of the product and finally the possibility of recycling the different materials that make it up for use in new applications.

So, before starting with the analysis of the product once its useful life ends, an option to extend it as much as possible will be given. To do this in the first place I had thought of promoting the sale of second-hand sticks in the Thunder store since most hockey players change their sticks long before their useful life. To be more specific, approximately 80% of field hockey players change their sticks every 1-2 years when they usually have a useful life of 4-5 years before they begin to cause deformations in it that cause them to lose utility or that they end up breaking.

For this reason, my idea is to incentivize field hockey players who have Thunder sticks to return the reusable once to the Thunder store and in return they receive a certain amount of money, in this way the incentive to do so is greater. The next step would be to sell these second-hand sticks on the Thunder Store at a much lower price. In this way we will be able to extend the useful life of these sticks and to get more profit from them since logically, the price of second-hand sticks will be a little higher than what will be pay to the players to return them to the store.

In addition, I have come up with an idea to extend the useful life of those second-hand sticks that have not been sold in the end. Currently in Catalonia there is a program for boys and girls from schools all over Catalonia to learn about field hockey. This program promoted by the Catalan Hockey Federation consists of organizing training days in which field hockey players and coaches teach the sport and at the end of each session the participants practise this sport. For this reason, it would be interesting to donate these sticks to the Catalan Hockey Federation to use them in these sporting events, thereby extending the useful life of the sticks and encouraging the growth of this sport and therefore, the possibility of increasing the number of potential buyers of the Thunder brand.

Finally we will talk about the possibility of recycling the different components of the ECOTHUNDER. In the case of this product we can only separate them into the stick itself, which is made of PLA matrix + flax fiber and the grip of the stick, which is made using recycled polyurethane (PU).

PLA + flax fiber recycling

Although it is a biodegradable material, that does not mean that it is easy to recycle. Currently I have not found information regarding the recycling of this composite to be able to use it again for the same purpose, but it is important to know that this area of additive manufacturing is advancing exponentially and it is very likely that soon we will see points to recycle this material and be able to use it again after certain processes for its recovery and recycling.

Recycled polyurethane recycling

Polyurethane can be recycled on more than one occasion while preserving its quality and properties, giving rise to raw materials with the same benefits as the original ones. Although this is true, PU can only be recycled in authorized recycling centres, so it must always be deposited in these centres or clean points. The recycling of polyurethane is a priori a simple process: polyurethane breaks down through different processes, either hydrolysis, amylolysis or glycolysis, the latter being the most frequent today. Once the corresponding process is finished, green polyols are obtained that are treated with additives and cellulose to obtain a useful polyurethane material again.

6.4 APPLYING LIFE CYCLE ASSESSMENT TO THE NEW STICK

In this section, the Life Cycle Assessment of ECOTHUNDER stick will be carried out. Thus, the objective of this section is to quantitatively assess if impact upon the environment have been reduced compared to the Thunder TH-Triskelion. Throughout the section we will see the goal definition and scoping, inventory analysis, impact assessment and interpretation of the results.

6.4.1 GOAL DEFINITION AND SCOPING

Defining the goal of the study

In this study the product to be analysed is a field hockey stick from the hockey brand Thunder Hockey. The main goal of this study is to quantitatively compare the environmental impact from the Thunder TH-Triskelion, which is one of the current stick models of the brand and the ECOTHUNDER, which is the new stick design after applying to it the Design for Environment methodology to see if it has been applied correctly.

The result of this study will be used for internal purposes such as learning about product development considering environmental impacts during the process, but at the same time, the study can also be used in external communication to inform hockey brands about how to design field hockey sticks in a more sustainable way.

Defining the scope of the study

In this study all the stages of the life cycle of the field hockey stick will be analysed from cradle to cradle, what means from the extraction of the raw materials that make up the stick to the end of life of the product.

The functional unit is a quantitative measure that provides a reference to which the inputs and outputs to the product system are related, which enables comparison of two different product systems. In our study, we will use the Environmental Impact Points as the functional unit, so we can assign an environmental impact value from 0 to 5 to each of the processes of the life cycle of the product and compare between the two stick designs easily.

The Thunder Hockey brand is dedicated to the manufacture of different field hockey materials. In the case of this study we focus only on the manufacture of field hockey sticks so for this reason, the material and energy inputs measured for the entire process, as well as the environmental emissions, must be assigned only to the analysed products.

6.4.2 INVENTORY ANALYSIS

In the inventory analysis section, all the processes that make up the stick will be analysed. That is why all the inputs and outputs of each of these processes will be analysed, which means that the materials and energy required in each process will be displayed, as well as the negative emissions against the environment that they produce and the losses of surplus materials in each of these processes.

In addition, as we have defined in the previous section, in our study we will analyse the processes analysed from cradle to cradle, what means from the extraction of the raw materials that make up the stick to the end of life of the product. Next we will see the inventory analysis for both Thunder TH-Triskelion and the ECOTHUNDER design to see the difference between both models.

Thunder TH-Triskelion

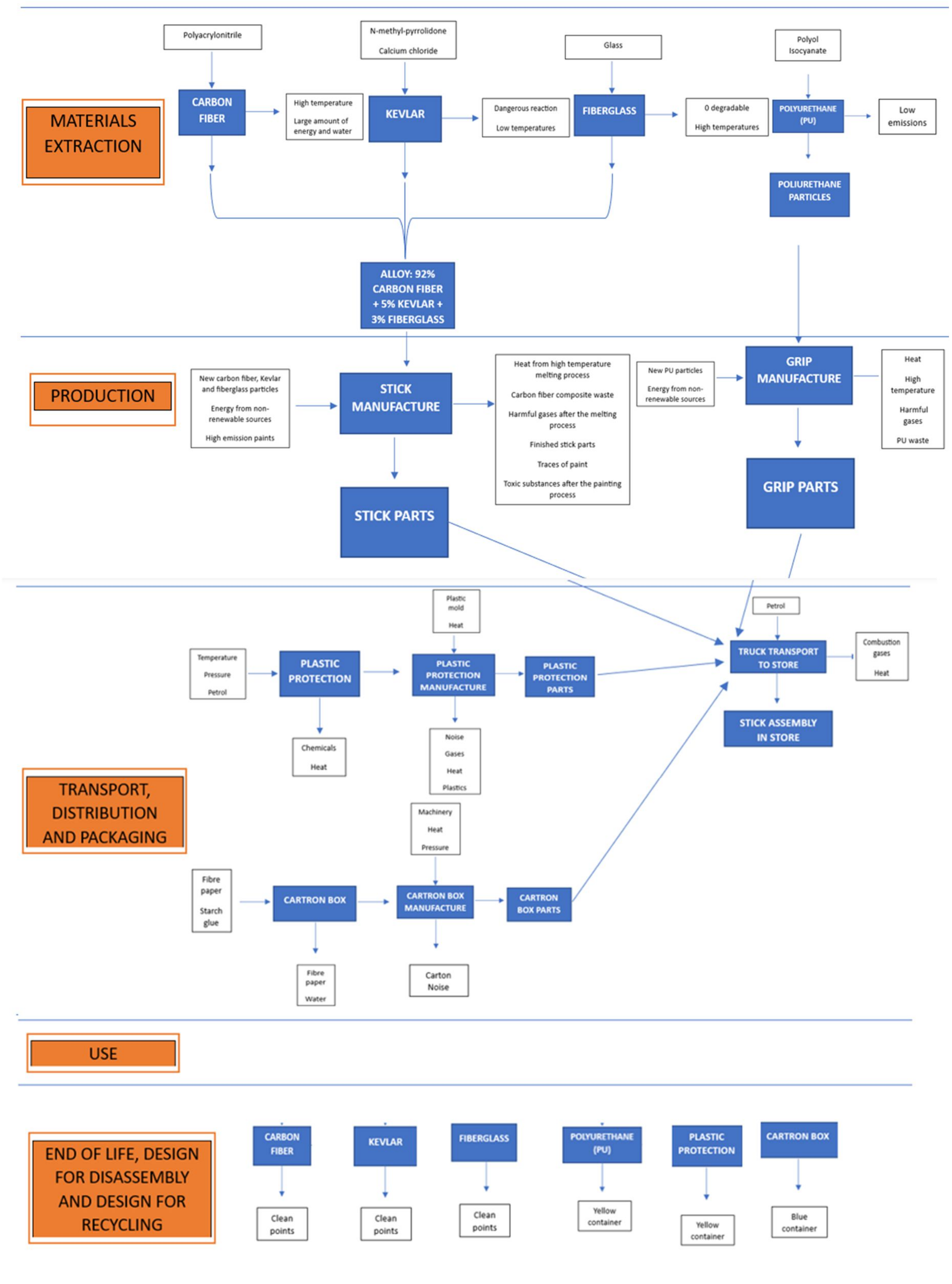

Figure 42: Thunder TH-Triskelion Inventory Analysis (Source: Own)

ECOTHUNDER

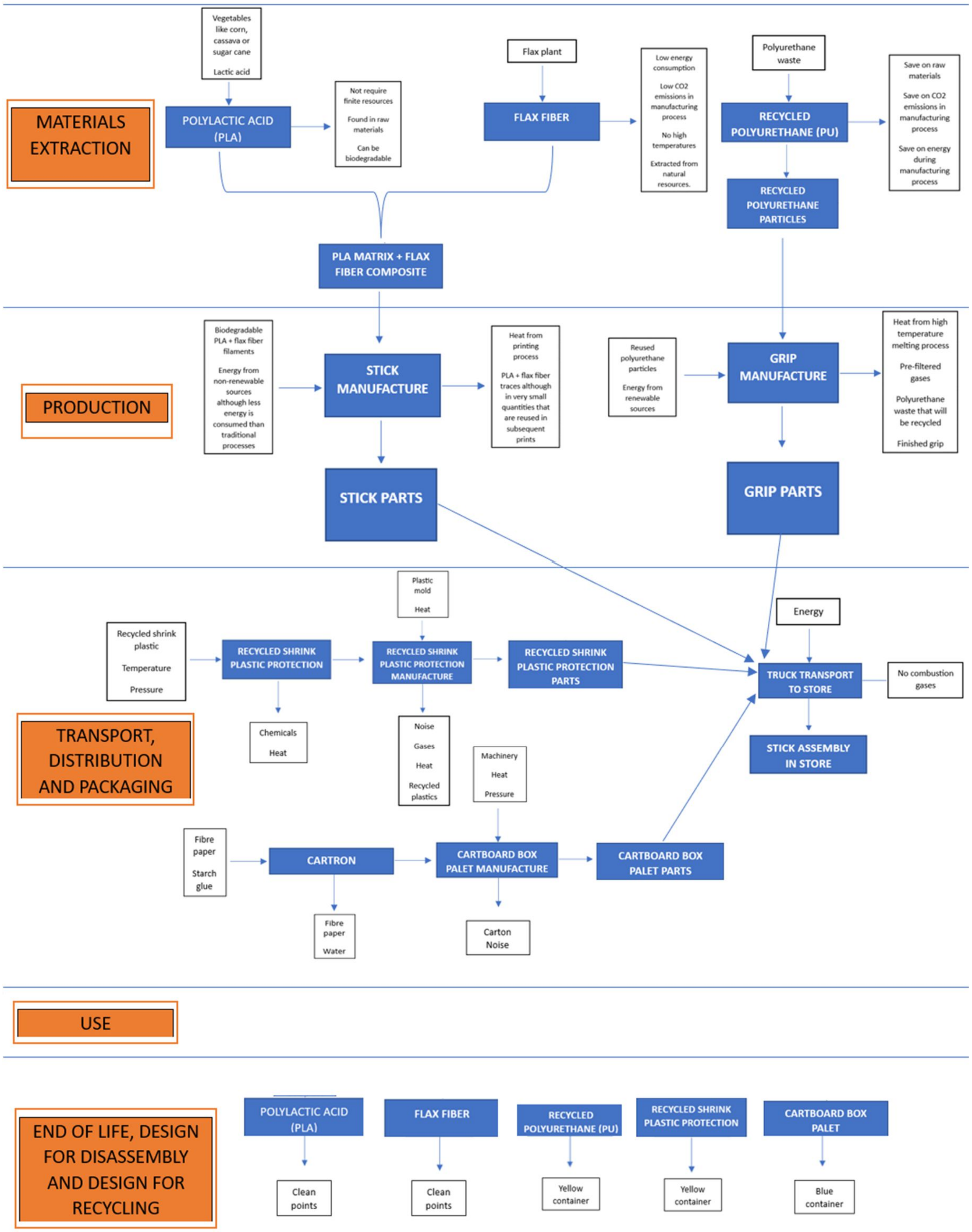

Figure 43: ECOTHUNDER Inventory Analysis (Source: Own)

In addition, in the third section of the Annexes named Inventory Analysis of the project it can be seen the inventory analysis from both designs in bigger and more clear images.

6.4.3 IMPACT ASSESSMENT

In this section it will be carried out the impact assessment, which aims to understand and evaluate environmental impacts based on data provided after the inventory analysis. LCIA generally consists of seven steps that we will see below:

1. Selection of impact categories, category indicators and models: This step consists in identifying relevant environmental impact categories to analyse. In our case study, we will use the most important ones, which are: Global Warming, Ozone depletion, Acidification, Eutrophication, Photochemical smog, Terrestrial toxicity, Aquatic toxicity, Human health, Resource depletion, Land use and Water use.

2. Classification: It consists in assigning the LCI data to the considered impact categories. The selection of these impact categories is based on the expected types of impacts. In our case study we will execute it in a more general way by identifying only the impact category of each of the processes and/or activities.

3. Characterization: This step involves the application of weighting factors or equivalence to unify all relevant substances within each impact category, which provides a way to directly compare the LCI results within each category. This is only necessary if the previous step has been done, it consists of assessing each impact with the use of a single substance.

4. Normalisation: The goal of this step is to establish a common reference to enable comparison of different environmental impacts. To achieve this aim, a reference quantity is used to make the data dimensionless.

5. Grouping: It consists in classifying the impact indicators by local/regional or global level.

6. Weighting: This step consists in determining which impact category is the most damaging and in what intensity in relation with the others.

7. Data quality analysis: The final step aims to obtain a unique result. For that reason the data quality analysis is done, but it is usually a controversial step, since, like the previous step, it is based on subjective considerations.

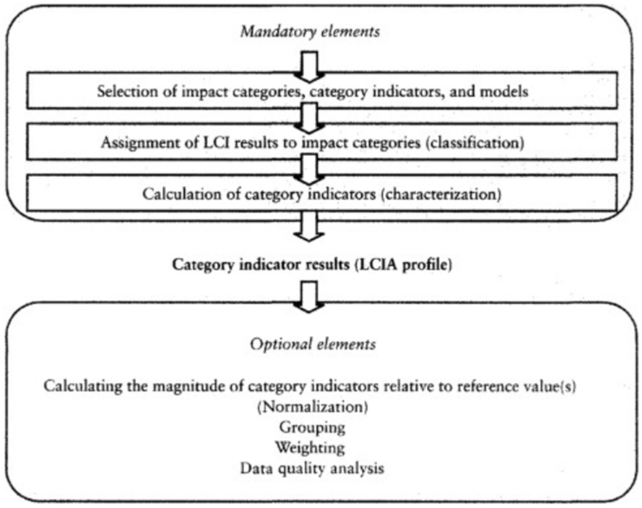

Figure 44: Elements of the LCIA procedure (Source: The concept of LCIA, 2023)

The aim of this section is to create two tables, one where I will analyse the impact assessment of the Thunder TH-Triskelion and another one analysing the impact assessment of the ECOTHUNDER design to be able to compare them.

But first I will explain how tables will be organised. On the columns of the table there will be all the environmental impacts that must be analysed during the LCA and in the rows we will find the activities that make up the different stages of the DFE to be evaluated.

In addition, each environmental impact to be analysed will be assessed by severity of the environmental aspects in the process with the terms impact (I), probability (P) and duration (D). Using this formula:

$$Significance = Impact * Probability * Duration \rightarrow S = I * P * D$$

Finally, I have classified the different aspects of the process to be evaluated with a number between 0 and 5, number 5 being the most severe with the environment. That way I can classify each environmental aspect by appropriate number.

VALUE	IMPACT SCALE	PROBABILITY OCCURANCE	IMPACT DURATION
5	International	Very likely	High
3	Regional	Likely	Medium
1	Local	Not very likely	Low
0	None	Improbable	None

Table 4: Values impact scale, probability and impact duration (Source: Own)

LCIA Thunder TH-Triskelion	Global Warming				Ozone depletion				Acidification				Eutrophication				Photochemical smog				Terrestrial toxicity				Aquatic toxicity				Human health				Resource depletion				Land use				Water use			
	I	P	D	T	I	P	D	T	I	P	D	T	I	P	D	T	I	P	D	T	I	P	D	T	I	P	D	T	I	P	D	T	I	P	D	T	I	P	D	T	I	P	D	T
MATERIALS EXTRACTION																																												
CARBON FIBER PARTS	5	3	3	**11**	5	1	5	**11**	3	3	5	**11**	0	0	0	**0**	1	3	3	**7**	1	3	3	**7**	1	1	3	**5**	1	3	1	**5**	1	5	5	**11**	3	3	5	**11**	5	5	5	**15**
KEVLAR PARTS	5	3	3	**11**	5	1	5	**11**	5	3	3	**11**	0	0	0	**0**	1	3	3	**7**	3	3	3	**9**	1	1	3	**5**	1	3	1	**5**	1	0	3	**4**	1	3	5	**9**	3	1	3	**7**
FIBERGLASS	5	3	3	**11**	5	1	5	**11**	3	3	5	**11**	0	0	0	**0**	1	3	3	**7**	1	3	3	**7**	1	0	5	**6**	1	1	1	**3**	1	5	5	**11**	1	3	5	**9**	3	3	5	**11**
POLYURETHANE PARTS	3	5	3	**11**	3	1	3	**7**	3	1	5	**9**	0	0	0	**0**	1	1	3	**5**	1	3	1	**5**	1	0	5	**6**	1	0	0	**1**	1	0	3	**4**	0	0	0	**0**	1	1	1	**3**
PRODUCTION																																												
STICK MANUFACTURE	5	5	5	**15**	5	1	5	**11**	3	3	5	**11**	0	0	0	**0**	1	3	3	**7**	3	1	3	**7**	5	5	5	**15**	3	3	3	**9**	1	5	5	**11**	1	3	5	**9**	0	0	0	**0**
GRIP MANUFACTURE	3	5	3	**11**	3	1	3	**7**	3	1	5	**9**	0	0	0	**0**	1	1	3	**5**	1	3	1	**5**	1	0	5	**6**	1	0	1	**2**	1	3	3	**7**	0	0	0	**0**	0	0	0	**0**
TRANSPORT, DISTRIBUTION AND PACKAGING																																												
PLASTIC PROTECTION	5	5	5	**15**	5	1	5	**11**	3	3	5	**11**	0	0	0	**0**	1	3	3	**7**	1	3	3	**7**	1	1	3	**5**	1	0	0	**1**	1	1	0	**2**	0	0	0	**0**	1	1	5	**7**
CARTRON BOX	5	1	1	**7**	5	0	5	**10**	3	0	5	**8**	0	0	0	**0**	0	0	0	**0**	1	0	0	**1**	1	1	1	**3**	1	0	0	**1**	1	1	0	**2**	1	0	3	**4**	1	3	1	**5**
PETROL TRUCK	5	5	3	**13**	5	1	5	**11**	5	3	5	**13**	0	0	0	**0**	1	3	3	**7**	1	1	3	**5**	0	0	0	**0**	1	3	3	**7**	5	3	5	**13**	0	0	0	**0**	0	0	0	**0**
USE																																												
------------------------------	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
END OF LIFE, DESIGN FOR DISASSEMBLY AND DESIGN FOR RECYCLING																																												
CARBON FIBER PARTS	5	3	3	**11**	3	1	3	**7**	3	3	5	**11**	0	0	0	**0**	1	3	1	**5**	1	1	3	**5**	1	0	3	**4**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
KEVLAR PARTS	5	3	3	**11**	3	1	3	**7**	3	3	5	**11**	0	0	0	**0**	1	3	1	**5**	1	1	3	**5**	1	0	3	**4**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
FIBERGLASS	5	3	3	**11**	3	1	3	**7**	3	3	5	**11**	0	0	0	**0**	1	3	1	**5**	1	1	3	**5**	1	0	3	**4**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
POLYURETHANE PARTS	5	3	5	**13**	3	1	3	**7**	5	3	3	**11**	0	0	0	**0**	1	3	1	**5**	1	1	3	**5**	1	0	3	**4**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
PLASTIC PROTECTION PARTS	5	3	5	**13**	3	1	3	**7**	5	3	3	**11**	0	0	0	**0**	1	3	1	**5**	1	1	3	**5**	1	0	3	**4**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
CARTRON BOX PARTS	3	0	0	**3**	3	0	3	**6**	3	0	0	**3**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	1	1	3	**5**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	1	3	1	**5**
TOTAL IMPACT ASPECT				**167**				**131**				**152**				**0**				**77**				**80**				**76**				**34**				**65**				**42**				**53**
TOTAL IMPACT PRODUCT																																												**877**

LCIA ECOTHUNDER	Global Warming				Ozone depletion				Acidification				Eutrophication				Photochemical smog				Terrestrial toxicity				Aquatic toxicity				Human health				Resource depletion				Land use				Water use			
	I	P	D	T	I	P	D	T	I	P	D	T	I	P	D	T	I	P	D	T	I	P	D	T	I	P	D	T	I	P	D	T	I	P	D	T	I	P	D	T	I	P	D	T
MATERIALS EXTRACTION																																												
FLAX FIBER PARTS	5	1	1	7	5	1	5	11	1	1	1	3	0	0	0	0	1	3	1	5	1	3	1	5	0	0	0	0	1	0	0	1	1	3	1	5	1	3	1	5	1	1	1	3
POLYACTIC ACID PARTS	5	1	1	7	5	1	5	11	3	1	3	7	0	0	0	0	1	3	1	5	1	3	1	5	0	0	0	0	1	0	0	1	1	3	1	5	1	3	1	5	1	1	1	3
RECYCLED PU PARTS	5	1	1	7	3	1	3	7	1	1	3	5	0	0	0	0	1	1	1	3	1	1	1	3	1	0	3	4	1	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0
PRODUCTION																																												
STICK MANUFACTURE	5	1	1	7	5	1	5	11	1	3	3	7	0	0	0	0	1	1	1	3	1	1	1	3	0	0	0	0	1	0	0	1	1	0	1	2	0	0	0	0	1	1	1	3
GRIP MANUFACTURE	3	5	3	11	3	1	3	7	3	1	5	9	0	0	0	0	1	1	3	5	1	3	1	5	1	0	5	6	1	0	1	2	1	3	3	7	0	0	0	0	0	0	0	0
TRANSPORT, DISTRIBUTION AND PACKAGING																																												
RECYCLED SHRINK PLASTIC PROTECTION	5	1	1	7	5	1	3	9	3	1	5	9	0	0	0	0	1	3	1	5	1	3	1	5	1	1	3	5	1	0	0	1	1	1	1	3	1	0	3	4	1	1	1	3
CARTBOARD BOX PALLET	5	1	1	7	5	0	5	10	3	0	5	8	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	3	1	0	0	1	1	1	0	2	1	0	3	4	1	3	1	5
ELECTRIC TRUCK	5	1	3	9	5	1	5	11	3	3	3	9	0	0	0	0	1	1	1	3	1	1	1	3	0	0	0	0	1	1	1	3	5	1	3	9	0	0	0	0	0	0	0	0
USE																																												
------------------------------	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
END OF LIFE, DESIGN FOR DISASSEMBLY AND DESIGN FOR RECYCLING																																												
FLAX FIBER PARTS	5	1	1	7	3	1	3	7	3	3	5	11	0	0	0	0	1	1	1	3	1	1	1	3	1	0	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POLYACTIC ACID PARTS	5	1	1	7	3	1	3	7	3	3	5	11	0	0	0	0	1	1	1	3	1	1	1	3	1	0	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RECYCLED PU PARTS	5	3	5	13	3	1	3	7	5	3	5	13	0	0	0	0	1	3	1	5	1	1	3	5	1	0	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RECYCLED SHRINK PLASTIC PROTECTION PARTS	5	3	5	13	3	1	3	7	5	3	5	13	0	0	0	0	1	3	1	5	1	1	3	5	1	0	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CARTBOARD BOX PALLET PARTS	3	0	0	3	3	0	3	6	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3	5	0	0	0	0	0	0	0	0	0	0	0	0	1	3	1	5
TOTAL IMPACT ASPECT				105				111				108				0				45				46				39				13				33				18				22
TOTAL IMPACT PRODUCT																																												540

6.4.4 INTERPRETATION

In this section , I will evaluate the information from the other sections of the LCA processes and interpret the results properly to understand if the DFE application on the field hockey stick has had some positive consequences related to the environmental impact.

Once the redesign of the field hockey stick had been carried out and the LCA applied, I can conclude from the results that the redesign has been more than satisfactory. Looking at the results, we can see that:

- Thunder TH-Triskelion: 877 Environmental Impact Points
- ECOTHUNDER: 540 Environmental Impact Points

Therefore, the redesign has allowed to reduce the environmental impacts of the product by 38'5%. Mainly what has allowed to reduce that percentages have been:

1. By changing the materials used in the manufacture of the stick for more sustainable and clean materials and even sometimes using recycled materials.

2. By manufacturing the stick parts using 3D printing technology we also reduce a lot the environmental impacts compared to the traditional methods of stick manufacturing.

3. Finally, optimizing the packaging, transport and end of life of the different components and materials of the sticks.

7 COST STUDY

Throughout this section, a cost study will be made of the Thunder TH-Triskelion and from the ECOTHUNDER, which results from applying DFE to the initial stick design. The objective in this case is to show the information in a simple and clear way using cost tables from both designs.

In addition, the price of production of one unit as a prototype is very different compared to produce a batch of hockey sticks considering the logic cost savings that are significally different when manufacturing a huge quantity of sticks, being able to be a 40% cheaper. For that reason I will create two tables for every design, one with the production cost of a single unit as a prototype and another one with the production cost from a 250 units batch.

Before showing the tables with production costs, it is important to remember that it is not essential to obtain a low price, moreover, in most cases the production of environmentally sound products is more expensive, which is not a problem since more importance is given to obtaining environmentally friendly materials and processes environment instead of economic. However, looking at the costs of this will allow us to see if the product can be commercialized.

THUNDER TH-TRISKELION 1 UNIT PROTOTYPE			
Name part	Unit price	Quantity	Total price
Stick part	103,77 €	1	103,77 €
Grip part	1,42 €	1	1,42 €
TOTAL			**105,19 €**

Table 7: Thunder TH-Triskelion 1 unit prototype cost study (Source: Own)

THUNDER TH-TRISKELION 250 UNITS BATCH			
Name part	Unit price	Quantity	Total price
Stick part	65,68 €	1	65,68 €
Grip part	0,87 €	1	0,82 €
TOTAL			**66,50 €**

Table 8: Thunder TH-Triskelion 250 units batch cost study (Source: Own)

ECOTHUNDER 1 UNIT PROTOTYPE			
Name part	Unit price	Quantity	Total price
Stick part	145,78 €	1	145,78 €
Grip part	1,83 €	1	1,83 €
TOTAL			**147,61 €**

Table 9: ECOTHUNDER 1 unit prototype cost study (Source: Own)

ECOTHUNDER 250 UNITS BATCH			
Name part	Unit price	Quantity	Total price
Stick part	92,35 €	1	92,35 €
Grip part	1,16 €	1	1,16 €
TOTAL			**93,51 €**

Table 10: ECOTHUNDER 250 units batch cost study (Source: Own)

8 CONCLUSIONS

During the realization of the final master's thesis, the objective has always been to design a more sustainable product, which means to design a product reducing its impact upon the environment. The reason why I have carried out this project is because I am aware of the problem that currently exists on our planet, where we are destroying it at high speed and I believe that as a society we must start acting now, even if it is whit a small contribution.

In addition, as engineer I think that we can do our bit to change the world, as we can think broadly and laterally, so we generally analyse beyond the problems and look for alternatives and solutions that perhaps have not been explored, looking for solutions out of the box and environmentally friendly.

The result obtained after realizing the project has been very satisfactory, as the initially objectives have been achieved, which were minimising the environmental impacts produced throughout the life cycle of the defined product as much as possible. In my thesis, more specifically I have used the Thunder TH-Triskelion which is a stick model from the hockey brand Thunder Hockey to which I have applied the DFE and LCA to obtain an improved version, the ECOTHUNDER.

After applying DFE methodology on the hockey stick by analysing each of its life cycle stages and realizing the LCA, that has allowed to quantify in a technical and objective way the changes made to the hockey stick after applying the DFE methodology, I can objectively demonstrate that I have fulfilled the objective of reducing the environmental impacts of the product, reaching a total reduction of a 38'5% between designs.

Another important point is that after redesigning the hockey stick, its manufacturing price goes from 66’50 € to 93’51 €, increasing by 40%. Even so, the commercial margin of this product is so great that there is no problem to commercialize the redesigned ECOTHUNDER version, for example the TH-Triskelion Thunder stick costs 66’5 € to manufacture while it is sold for €279. In addition, the sale price of the ECOTHUNDER may rise due to its characteristics of responsibility with the environment.

As a result, I have designed a field hockey stick that is committed to a more sustainable world and the design is enhanced to guarantee a long useful life, satisfying at all times the needs detected in field hockey players.

9 POSIBLE FUTURE RESEARCH

In this section I will give some other option of interesting projects related to the theme of this project. During the realization of the project, the truth is that different options have arisen that I have found interesting to investigate and do research.

First, I would like to mention one type of project that I found so interesting that I even considered applying it to my own. My project consists of designing a product applying the Design for Environment mentality. The proposal consists of redesigning an existing product applying the Design for Environment mentality, in this way the original product could be compared with the new product to see the improvements.

As I have seen during the realization of the project, the application of the Design for Environment and Life Cycle Assessment mentalities has increased greatly in recent years and the tendency will be to increase even more exponentially as society each time is more aware that the change towards a future with a world more respectful of the environment is more necessary. For this reason, another project that I find interesting would be to investigate the possibilities of strategies and methodologies that will be used in the coming years in the field of DFE and LCA.

Finally and as a fan of field hockey, after the completion of this work where I have seen in a more theoretical way the possibilities of resources to design a stick of field hockey in a sustainable way, the next step, which would make me very illusion would be to get in touch with a brand of field hockey sticks to take the project forward and try to manufacture in real life the stick I have designed in this project to be able to see the real differences it has in the environmental impacts and also to verify its functionality.

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