Master Thesis:

How eco-design tools can be implemented in the product development process of a company: A case study on bicycle helmet

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Abstract

This study was performed at the facility of Intersport France (Ile-de-France, 91), at the department of Sourcing, Quality and Development team.

The purpose of this work is to evaluate the benefits of eco-design tools for large companies with important economic constraints, such as Intersport, and the types of products that can emerge from their use. To do so, I have described the general process of product development first and compared with the process of Intersport. It allowed me to understand how the eco-designing part can be implemented in the product development process. I, then, worked on the different sustainable initiatives implemented in the industry and more specifically at Intersport. After that, a set of different eco-design tools were selected due to different parameters of evaluation, to choose exploitable tools for a novice team. The choice of the product that would be developed was made on a bicycle helmet, because of its technicity and the use of plastic, which is a similar aspect of many of the other products developed by the SQD team.

After having described the technical decomposition of the bicycle helmet, the use of two tools: the TRIZ contradiction matrix and the Life Cycle Assessment, allowed to find that the best compromise for an eco-designed helmet is a composite liner with EPS and cork. This product was already developed by another brand, expert in the industry of bicycle helmet, which confirmed the scalability of the project. Based on environmental criterion such as CO_2 emission, this product was compared to carbon shell helmet and standard helmet, as they are the most representative helmets currently available on the market.

Finally, the results of the tools were exposed to the SQD team, to see if the eco-design tools used can be transmitted and used by every product developer. The results were mitigated, since the use of the tools was not easy to understand enough to be used by everyone, but the environmental aspect was considered seriously.

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Glossary

Acronym	Meaning
2D	2 Dimensions
3D	3 Dimensions
ABS	Acrylonitrile Butadiene Styrene
ADEME	Agence De l’Environnement et de la Maitrise de l’Energie
AMIS	Advanced Material for Innovation and Sustainability
ASIT	Advanced Systematic Inventive Thinking
BAH model	Booz, Allen and Hamilton model
CO_2	Carbone dioxide
DDPP	Direction Départementale de la Protection des Populations
E-PLA	Engineering Polyactic Acid
EcoASIT	Ecological Advanced Systematic Inventive Thinking
EPP	Expanded PolyPropylene
EPS	Expanded PolyStyrene
EPU	Expanded PolyUrethane
ESQCV	Evaluation Simplifiée et Qualitative du Cycle de Vie
EU	European Union
GOTS	Global Organic Textile Standard
GRS	Global Recycled Standard
IIC	Intersport International Corporation
INP	French acronym meaning Polytechnic National Institut
IPE	Individual Protection Equipment
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LED	Light-Emitting Diode

LiDS	Life cycle Design Strategies
MAC	Micro-Agglomerate Cork
MET	Material Energy Toxicity
MOQ	Minimum Ordered Quantity
MVP	Minimum Viable Product
OCS	Organic Content Standard
PC	PolyCarbonate
PET	PolyEthylene Terephthalate
PIT	Product Ideas Tree
PP	PolyPropylene
PS	PolyStyrene
PVC	PolyVinylChloride
QR code	Quick Response code
SALi	ZIRCAR Ceramics' Alumina Type
SC	Scope Certificate
SQD	Sourcing – Quality – Development
TC	Transaction Certificate
TPU	Thermoplastic PolyUrethane
TRIZ	Russian acronym meaning Theory of inventive problem solving
VOC Method	Voice Of Customers method
WBCSD	World Business Council for Sustainable Development

I. Introduction

For the past decade, a lot more industries have been willing to reduce the negative impacts of their product during their life cycle. Firstly seen more as a source of constraint than a competitive advantage due to the different norms being implemented, environmental care has become more than a technical problem over the years (1). Nowadays, it has become a tool for developing innovative products and results toward economic benefits of the implementation of the ecological aspect in the product development (2).

Among them, Intersport has been willing to change and to restructure their production method through the consideration of their environmental impact. Among the Sourcing, Quality, Development team of Intersport, in charge of the development of the own brands of Intersport, the concern is on the sourcing of the product and the ability to trace the materials. Projects such as the Green Series label, whose implementation in the Intersport stores will begin near 2023, are thought to implement more recycled materials to match the customer's needs. Indeed, Green Series is a label put on products that are composed of at least 50 % of recycled or bio sourced materials, for instance recycled polyester or bio cotton. Thus, the product development process is even more turned toward eco-made products that would go alongside this type of project.

The product development team is divided into two parts which are interdependent: the textile and product part. On the product side, Benoit Penven, my advisor, is the product development manager and responsible for the choice of the product developed for the own brands of Intersport, which are Nakamura, Energetics, McKinley and many others.

The SQD team is in competition on the product development part with Intersport International Corporation, which is an organization made from the gathering of ten purchasing centers to develop the other products of the own brands of Intersport. The difference between the SQD team and IIC is that the latter creates products for all the Intersport stores in the world whereas the SQD team is developing product for the French stores only.

As the assistant of Benoit Penven among the product development team, my role is to help with the creation of products for the incoming seasons and help to ensure the quality of the products received by the suppliers and the regulation of the orders. There must be a balance between attractive prices, better quality products and in accordance with the need to be able to be selected by the stores when they need to make a choice between IIC and our products.

The SQD team has shown through the creation of various products such as backpacks or helmets the ability to design interesting sporting goods for customers. However, there is a difficulty which comes from a divergence of will: The company wants to develop products more respectful of the environment whereas the SQD team needs to develop new products interesting for the company, which means easy to sell and relying on similar products than those already available on the market. With these constraints, it becomes difficult to conduct the creation of innovative products that will be neither patented, nor necessitates new manufacturing machines, nor be at a too high selling cost while answering to environmental concerns from the customers and the company.

In this study, several concepts for the development of more environmentally friendly products will be used to find a solution to this problem of divergence of objectives. Among those concepts, the one at the core of the debates is eco-design. Brezet and Van Hemel define eco-design as "the consideration of the environmental perspective on all the process of product development, inducing the least important impact during all its life cycle" (1997). This concept has seen its popularity skyrocket among industries, alongside the principles of circular economy, despite several differences (3). The purpose of this study will be to find eco-tools that could be used by the company to develop an eco-designed helmet and see if their use can be systematized in the product development process of the SQD team.

The choice of the product was made on a bicycle helmet for several reason. Not only is it a technical and one of the leading products of the SQD team that have several possible approaches for implementing eco-design in its designing process, but it is also has the characteristics of many plastic products: It is cheap, easy to manufacture in large amount and resistant. Using tools to understand how to bypass the use of plastic in such material would help to extend their use to other products made on the same principles.

In order to find a method for developing an eco-conceived helmet, a setting of different eco-design tools available will be deployed and evaluated through their relevance with the vision of the company. Thanks to these eco-designed tools, the idea of this work will be to obtain a concept of eco-designed helmet that will be compared to the current alternatives available on the market for the purposes of a company of the size of Intersport. Indeed, Intersport France is a cooperative that works together alongside adherents and proposes products, which can be bought or not by the adherent. The cooperative represents more than 300 people working in collaboration with 650 stores, and a turnover over two billion euros, which makes it the largest distributor of sports equipment in France, but also in the world with more than 5500 stores allocated in 66 countries (4). These factors induce expectations toward customers and thus a lower flexibility. This way, the applicability verification will be done by detailing the methods of operation at Intersport and how an eco-designed product, in terms of prices, methods used and technologies available, can be implemented in order to develop the corporate social responsibility of Intersport. All these considerations lead us to the following question:

How eco-design tools can be implemented in the product development process of a company: A case study on bicycle helmet

In the first part of the study, the product development process is explained by describing the global method of operation. Then, the principles of eco-design will be explained. The development of different tools helping to ease the creative process and implement eco-design concepts, some of them selected on their pertinency and their type, are explained later in the literature review and used in the experimental part, considering its limits for each of them.

A concise description of current bicycle helmets and their composition as well as the different technologies developed in this industry will help to know which part of the helmet will be the most interesting to work on. Then, the description of the different tools will help to adapt the choice of the most pertinent tool that will be used in the case of Intersport. By using these tools, the possibilities to develop an eco-made bicycle helmet will be explored. When the concept of an eco-designed bicycle helmet will be found through these tools that matches Intersport and customer's needs, it will be compared with current offers from other brands with the most adapted eco-tools available and then evaluate the outcomes through a LCA software to understand the differences and, if there are, the benefits of our product compared with the others available. Lastly, the results will be presented to the team to see the applicability of the tools in the company.

II. Literature Overview

1. Product Development processes and methodology

In this chapter, we will approach the product development methods and extract the general steps used in every case of product development to dress a portrait of product development.

i. Description of the process

Product development refers to the different stages of creation of a product, from the concept to the market release. It is the conversion of the customer's need into a technical solution. However, there is a certain difficulty to structure and draw up the development process of a product. This difficulty comes from the complex relations between constraints and the innovative part, which makes the product new and difficult to rely on already existing similar products. Howbeit, it is possible to highlight different general processes.

From a structured point of view, by following a general model that has been generalized and recovered by several experts in this area such as Ulrich & Eppinger (2015), it becomes possible to process one step at a time to the different stages of the product development. It allows to have a broader vision on the entire product development from cradle to grave. It becomes possible to describe these stages in several bullet points that can be generalized to most of the product development processes and are the results of different works from Ulrich & Eppinger, BAH model (Booz, Allen and Hamilton model) and other similar models. These different steps can be split in seven parts:

- Creation and organization of a team,
- Identification of the need, Idea generation,
- Scoping/Screening,
- Concept development,
- Creation of the product,
- Validation and launching,
- Evaluation.

These different steps are explained in detail in the next parts, and how they are facing possible improvements.

ii. Creation and Organization of a team

First of all, the product developers must consider the importance in the creation of a team during product development (5). As a various composed team helps to understand with a broader vision the market needs and planning. Majchrzak depicted three diverse types of teams: functional, for a slow-moving but well-established product, self-organized teams for small projects and, by extension, a small team, and cross-functional teams, constituted of elements with different areas of expertise but interdependent (6). Carter (2021) explains that a cross-functional team that remains well-constructed and interdependent is a common aspect for product development. Di Benedetto depicts the significant improvements made on product launches for a cross-functional team (7).

Majchrzak highlights that these types of teams are more interdependent teams with special skills used for a common goal, whereas a real team needs to have interdependent members bringing their expertise for a shared task (6). Likewise, to the different parts of the human body (head, back, legs, arms…), the ability to work in cooperation with each other allow a general movement of the whole body. This way, roles can be defined to deliver responsibilities to everyone depending on their sector of activity:

- The product owner, who will oversee organization, and who is able to provide help to each other member,

- The dispatcher, who can understand the big picture and delegate the tasks accordingly to each member depending on their skill. It can be in small teams the product owner,

- The developers of the product,

- Quality assurance resources, who ensure the quality of the product at each step of the process.

By acquiring this minimum set of team members, it becomes possible to have clear and essential roles for everyone without unnecessary ones. From this point comes now the necessity to facilitate each of the product development milestone.

iii. Identification of the need, Idea generation

According to Gloria Barczak and Anthony Di Benedetto, the identification of the need implies the evaluation of the scalability of the project, identification of the problem that needs to be solved (8), (7). It may involve research and data collection through survey or discussion with potential customers. All the information about the potential users, objectives and strains are detailed just after this part. There is a conceptualization part where the product is examined and determined as well as its specifications and its purpose (7).

At the start of the process, the identification of the need can be done in two ways: top down or bottom up. Top and bottom referring here to a hierarchy perspective, which are divided here respectively in the highest level of direction and the thinnest. The former uses a problem that the highest level of hierarchy encounter to find solutions adapted to that, and the latter, less structured, comes from the intuition of the users and ascends to the decision makers to find a solution. These two methods for identification have their benefits and pitfalls but the global picture that can be drawn is that the top-down method is more related to classic problem-solution schemes, whereas bottom up is related to experiment from customers. It has the benefits to be more representative of the real issues but has several problems. According to Richard Feynman on its report on the “Challenger” space shuttle crash in 1986, top-down method can induce errors of scope if the decisions are made too quickly and does not allow changes in the designing part (9). It is important to let the qualified people implement their ideas in the process.

"If I had asked people what they wanted, they would have said faster horses."

Henry Ford

iv. Scoping/Screening

Scoping is the selection of the potential ideas that could be viable. In this part, the bill of materials composing the products are identified. It allows to evaluate the market part of the product, including its potential price, if the product can be profitable while meeting the customer's demand. This step also consists in evaluating the technical aspect of the product: Is it technically manufacturable? Will this be at the detriment of the target price (8)?

This part necessitates a high level of generation of ideas. Numerous methods were developed to facilitate this part of the process. Here is a non-exhaustive list of methods commonly used:

The Voice of Customers method consists in gathering data among customers while considering their need according to their own words. It allows to trace the user's way to the product, what is their struggle while using it and allow to have a better apprehend it. One example of this method can be the setting up of a request identification system for customers to identify their needs.

If reaching a large amount of customer's perspective can be too difficult, another possibility for idea generation can be internal search. It is mostly known as brainstorming. Brainstorming is a technic of idea's research based on the communication developed in 1940 by Osborn (10). According to Kirjavainen & Hölttä-Otto, selecting the conditions for brainstorming allows to find other ideas that would have not been though about otherwise (11). For instance, writing instead of debating eliminates self-censorship and allows to take out the best of everyone and not only the most vocal people.

The benefits of brainstorming are numerous. Lahdenne points out that such tool is a facilitator and a generator of idea (12). It must develop several rules to be organized and constructive, including the deferring of judgment, time limitation, focus on topic and limitation of one conversation at a time. The number of ideas created gives a large amount of material to work on and beginning of ideation. Despite the problems highlighted by the detractors of this method such as the poor-quality ideas generated (13), it remains a largely used process in many teams.

Considering the time management, a method considering its importance and the necessity to not scatter into many ideas, which are not for all of them relevant, is the State-Gate model. It is a model commonly used by societies (14). It consists in a series of activities (stage) done, and evaluation of the relevancy of these activities (gate). This model has the benefits to be a good screening process by splitting the ideas and focus the research on the most interesting ones.

Finally, two major issues can result at the end of the screening process: rejecting a viable idea or conserving a good one, which can cause a long-term profit loss. Therefore, it is important to select the right criteria that will evaluate the quality of a product. The importance of selecting the right criteria and ranking them by giving more or less weight is due to the cost it can engender.

v. Concept development

This part is the transformation of an idea into a tangible concept. It does not need to be a real product at this point, even if the design made must not exceed technical limits, but it needs to be already a clear enough concept to evaluate the customer's answer to it. It allows many feedbacks, which can be internal or external, and an evaluation of the scalability of the project. It overlaps in a certain way with many other stages of product development because it gives the consistency of the product development. It is the last part of the work before the designing and the development of the product.

The last part constituting the predevelopment process is the constitution of the business model, consisting in an evaluation of the potential competitors, the market size, the strong and weaknesses of the product or the customer's tendencies. Cooper points out the necessity of the business analysis after product design as it proves that the product is able to answer to a need from customers (15).

Several methods are used during the business analysis. There are tools helping to convince investors such as a roadmap, which is a representation of the actions to make to reach the objectives or a budget cap. These tools are used to schedule the evolution of the project and give a plan to follow. Some other tools are destined to evaluate the number of people who can be logically targeted by the product such as market estimation methods, made through calculation and giving credit to the feasibility of the project. This stage engenders plenty of marketing tests, sourcing tests and performance.

The pre-production process represents an important part of the whole product development. Indeed, there are models for product development process without preproduction processes, such as the lean approach. Developed by the Toyota company, this method can be extended to other domains that car industry. It focuses on the research of maximum performance and waste reduction, waste being not only about material but also transportation, useless steps or waiting (16). This method, despite the numerous benefits it can obtain in the production chain, has some limits since pre-production originates up to 85 % of the problems during production (17). The fact remains that the lean approach permits a great time management and optimization. Currently, less than the quarter of the time spent by the engineers working on products is used to add value to the product (18). By splitting worker's part and waste cuts, there could be a lot more possibility to spare the time in added value.

vi. Creation of the product

Once the idea generated and the business model elaborated comes the actual designing. The design part plays an important role in the development of a product. It considers the design part as a redesign of an already existing product in most of the development processes (19). From this, it is possible to remove unnecessary iterations and accelerate the process.

Johnson precises that at this stage begin the works on the components that will constitute the product, that must be absolutely corresponding to the design made in amount to prevent any issues later on the product (20). It cannot allow any misinterpretation or lack of precision. To do so, it can be possible to design a 2D or 3D representation of the product, for modelling. The benefits of using 3D representation on a software is the ability to test the components and their properties based on a model. This part is even more important for mechanical pieces such as gearbox but can also be applied to more basic products such as helmet to test their resistance to impacts.

This point leads to another, which is the creation of the first prototypes, which have the basics characteristics that need to be developed and evaluate if the functionality is understood. The objectives of a prototype are to test as quick as possible the product and to have feedbacks on it. The first prototype that will allow to validate the customer interest is called the Minimum Viable Product (MVP) (21).

This part is the most technical one. It generally involves at least laboratory's researches in amount to meet the exact specifications required by the product, and manufacturing methods to determine the best way to take into account all the parameters, such as environmental or production, to manufacture the product at a larger scale (22). The customer's feedback remains predominant at this point to avoid going in the wrong direction of the development (12).

vii. Validation and launching

At this point, the functionalities of the product are tested to see if the product is viable, and the latter being finally released into market, followed with advertisement and promotional activities. There are also marketing tests, which constitutes the most expensive part of the product development, mostly because it helps preventing important failures in the launching (23).

The final test done before the actual launch of the product is called market testing. The purpose of this test is to try the product in a real-world condition (6). It includes sales estimations and financial performances. The difference with initial tests is in the decision making, as at this point, the consumer can decide without any constraint to buy the product or not, which makes the product in direct competition with the other similar products. Despite the optionality of this stage, it helps to have an idea of the reaction of the customers toward the product and allow final adjustments before endorsing the launch (7).

viii. Evaluation

Lastly, a non-neglectable aspect of product development is the post launch review. It can be evaluated by the customers but also inside the company. To evaluate the success of the product, the developers need to verify if the product met the objectives targeted earlier in the development process, and if not, explain why. It can be cultural such as the language of advertisement, political (because of specific regulations that were not considered) or linked to service or product failure (24).

This stage was not much mentioned in most of the product development processes found but remains important in order to ensure the sustainability of the product on the market. From another perspective, Hogan highlights the importance of giving credits to the customer's feedbacks and the value the product is bringing to them more than concentrating on the product (25). These bullet points pinpoint the importance to consider the lifecycle of the product from the very beginning until the end of life when it comes to decisions on the product development (26).

Broadly speaking, many strategies evoked have their particularities. But it is important to highlight the common points between all these models: These different methods can, for most of them, be linked together, which is the reason why we decided to make a global approach of the product development that gathers the important steps underlined by each method. Hence, the following chapter will mostly focus on how eco-design can be part of the product development, and how it is done through some examples such as the recycling concept or label implementation in the company. This will lead to the exploitable tools for eco-design currently available.

2. Approaches for a responsible product development

i. Circular economy and eco-design for companies

Many different designations are affected to the necessity of preserving the environment. Among them, a confusion is often made between economical circularity and eco-conception.

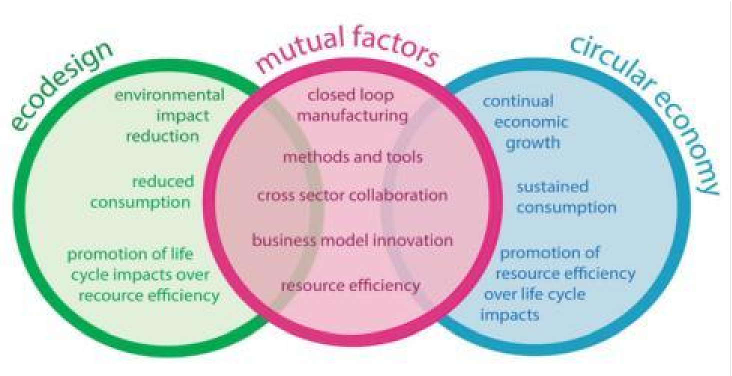
Circular economy focuses on the material or the optimization of their use, which means taking the maximum advantage of the product and regenerating the used product into a new resource (27), which is a cyclic principle. However, it is difficult to achieve circularity at the moment because of the lack of infrastructures for recycling. This way, most of the time, the product is used at its maximum before it becomes unusable (28). As a matter of fact, the recycling process of materials can't be a long-term benefit in circular economy since at a certain stage, the recycling process would not allow to benefit from the products recycled (29).

Indeed, the recycling process necessitates the injection of new components, especially in the fabrics, otherwise, the material becomes damaged and lose its properties. Exceptions remain as aluminium, which is fully recyclable and do not lose its property through its process (30). Still, its degradability takes hundreds of years and putting to waste elements that can be recycled without losing their properties can be a problem. Indeed, half of aluminium is recycled, the other half can be lost before the process of recycling.

On the other hand, eco-design aims to reduce as much as possible the environmental impact of the product. Eco-design foresees the use of the product in a long term and prevents the potential problem since the environment is at the crux of the conception (2). The different aspects of the product are considered, not only its lifecycle but also the concept of the service, e.g., what is it used for, for which purpose and by whom.

The difference between circular economy and eco-design, according to Sharon Prendeville, is that circular economy has as a main pitfall a compulsory adaption to the consumers, which can lead to overconsumption (31). The benefits of circular economy are, at first glance, enormous but it is difficult to apply them to our current system, not only because of the technology limits, but also because of the principle of a closed system: As the transformation of the wastes into new products consumes energy, the latter needs to be brought from an external source (32).

However, eco-designing is not always beyond reproach. McDonough and Braungart pinpoint that it is in contradiction with the economic growth, due to its cradle-to-cradle politic that limits the consumption. Its definition itself makes it difficult to meet with the objectives of corporations. Plus, the difficulty to evaluate the benefits of eco-conception through tangible tools makes it looked like greenwashing only. It needs to develop a rigorous evaluation methodology (33).



Shape 1 : Relationship between Eco-design and Circular Economy (34)

Considering the benefits and pitfalls of eco-design and circular economy, the rest of this study will try to reach appliable solutions and focus on the former, since the short-term limits of circular economy make it not a usable strategy to rely on in the development of environmental-friendly products.

From an industrial perspective, the review of the texts from Van Hemel, ADEME and WBCSD (World Business Council for Sustainable Development) allows to point out the benefits of environmental consideration: Eco-design gives advantages from the perspective of economical savings, increasing of revenues and, by extension, creativity of the company.

Indeed, the lower costs of recovered materials in the process of creation of new products makes it an interesting concern (34). Moreover, it opens the company considering eco-design to potential new market. After a study made by the ADEME, the latter identified three types of profits for the society (35) :

- Cultural heritage: 86 % of the interviewed companies witnessed an improvement of the society vision. It can become an argument for the company which become a competitive advantage,

- Customer: More than a third of the companies saw a better relationship with the customers. It allows a differentiation in a marketing point of view,

- Ethical: By implementing the social responsibility of the company, they found an increasing of 40 % of the motivation of the employees and a better ability to conceive new products.

But these considerations must be taken cautiously. As a matter of fact, many customers are embracing the initiative but are still reluctant to pay the price for it (36).

Most of the time, economic and environmental perspectives converge without initial consideration as shows the example of packaging reduction (37) : Indeed, packaging waste's reduction allows to reduce the amount of material ending up in landfills or even recycled (which consumes energy), while at the same time allows profits for the manufacturer, since the production of a lower amount of matter induce a decrease in costs. It has been calculated to be around 100$ per ton of waste in metropolitan areas in Canada.

Eco-design remains not enough taken into consideration and is nowadays promoted through regulations to be efficient and a source of improvements, for the company and the environment. In the design for sustainability approach, it has been shown the need to split production efficiency and sustainability goals at early stage of production to allow the reduction of costs (28). This approach points out the necessity to reduce the pollution from the cradle: by considering the environmental strains at early stage, all the following processes such as choice of materials, logistic or end of life keep this objective and reduce the polluting flows.

ii. Recycling of plastics

As helmets are made of plastics in most of the cases, the most obvious consideration that can be made before production of an eco-designed helmet is considering the process of plastic recycling and if it can be used in this case. Broadly speaking, the use of oil-made material represents a large part among manufactured products, and a lot of research are made on the recyclability of plastics. As a matter of fact, no labels toward eco-designed product are mandatory for now. The existence of mandatory labels concerns only energetic consumption (38). Thus, it depends only on the will of companies to develop eco-designed products to have certifications such as GOTS certification that they will highlight through marketing.

First, the shell has been worked to be less impacting from an environmental perspective. Possibilities to recycle the plastic used for the shell by adding other plastics into this one were explored (39). Indeed, injecting certain plastics in already used ABS, for instance, in controlled proportion gives several benefits: It decreases the quantity of plastics used for the manufacturing of a new material while conserving the strength properties. Moreover, some materials, especially plastics used for electrical devices, are contaminated by the contact with other toxic materials. Mixing the plastics allows to improve the quality of the whole. Nevertheless, the used plastics need to be compatible, and can be evaluate in terms of compatibility as it is shown in the following table:

Table 3 Compatibility of Plastics

	PP	PS	ABS	PVC
PP	O	O	X	X
PS	O	O	X	X
ABS	X	X	O	O
PVC	X	X	O	O

O: Good compatibility, X: Poor compatibility

Table 1 : Plastic compatibility, Murakami (2001)

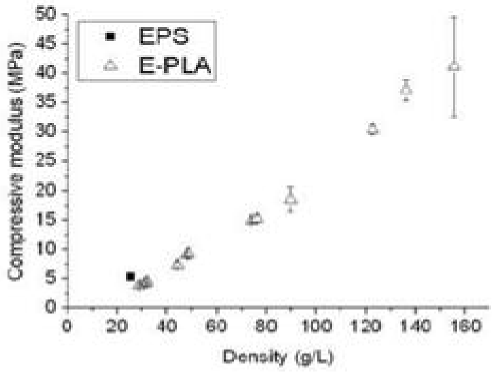
One of the processes to compound recycled materials with a new one according to Murakami (2001) is Sandwich Injection-Moulding Process. It consists in forming a multi-layer with two sorts of materials: the skin, a thin structure made of the new material and the core, the largest part of the whole compound made of recycled EPS. The skin material envelops the core material so that the impurities in the core are encapsulated and will not contaminate the rest of the material. This way, properties of the material can be increased: for instance, a hybrid made of EPS in the core and ABS as the skin delivers to the product a high impact strength (38).

Other methods of recycling PET exist, such as granulation, dissolution or reprecipitation with the inconvenient of being difficult to make it economically workable. Therefore, the process is not exploited yet (40).

From a general perspective, a lot of plastics constituting a helmet can be recycled, just as PET or ABS. But considering that recycling is the solution for all plastics is a generality that omits several problems induced by this process (41). Firstly, recycling EPS, which is the main component of bicycle helmets, is harder than for other plastics since it is composed of over 98 % of air, which makes it expensive to transport (42). Added to that, the material is used mostly for transportation, and depending on the product transports, hazardous contaminants can impregnate the EPS.

Secondly, recycling plastics consists for most in grinding and melting the plastic to make a filament that will be reused. But this process degrades the material every time it is applied (43). Indeed, the difference of crystallinity induced by using recycled plastic exhibits a brittle behaviour for the recycled plastic whereas a virgin one will be more ductile. This way, it cannot be recycled repeatedly, and it creates lower quality material, which is called downcycling. Therefore, to keep an equal level of quality, the recycled material must be mixed with a virgin version of the same material (or another virgin plastic as it has been seen with the sandwich injection moulding process). Moreover, using recycled materials induces particle contamination, which is exactly what needs to be prevented when recycling a material, as it will deliver microparticles unable to be filtered (41).

Added to that, several companies such as Giro began to use an alternative to EPS: E-PLA. Standing for Expanded polyactic acid, it can be obtained from corn starch and is often used for 3D printing. But despite being called degradable, E-PLA not only takes a couple of hundred years to degrade (44), but it also needs to be created in specific industrial whose industries are few to exist. Thus, it could indeed replace EPS as it supports similar mechanical properties while producing less greenhouse gases, but it needs investments to be scalable (45).



Shape 2 : Compressive properties of E-PLA and EPS

Broadly speaking, to address the use of plastics, materials made of natural components were tested to find a 100 % natural fibe solution. Some materials used as alternatives for the liner or shell are coconut, sisal, and cork (46), (47), (48).

A study by Totla (2020) performed on a coconut for the shell and banana fibers for the liner allowed to test its deformation under stress (46). It has shown to undergo less deformation than ABS hard shell helmet in static analysis but also undergoes a lot more stress while showing higher deformation. Thus, by selecting the right enforcement to match the coconut, this material could be as useful as ABS.

R.M.Coelho et al. (2013) worked from their side on the use of Micro-Agglomerate Cork (MAC) as alternative for the liner (47). The benefits of this choice compared with EPS as a liner are that it acts like a spring and can recover its first form after an impact, at the price of a higher weight (density of 290 kg/m^3 against 120 kg/m^3). Micro-agglomerate cork was preferred to natural cork because of its anisotropic properties, which means a more predictable answer to a physical strain. The results shown that the EPS foam protects the best as it reduces the most the acceleration felt by the head, but this result is only appliable for the first impact. After that, the EPS cannot recover its original form and will be much less efficient. To counter this issue, the EPS was mixed with MAC in differrent proportions. A compromise was made between the possibility to reuse the helmet and the peak of intensity felt during an impact, which will be all the higher if the amount of EPS decreases. Still, not many companies have begun to use this type of product at the moment, as the use of plastics remains cheaper and easier to manufacture (49).

iii. Sustainable initiatives at Intersport

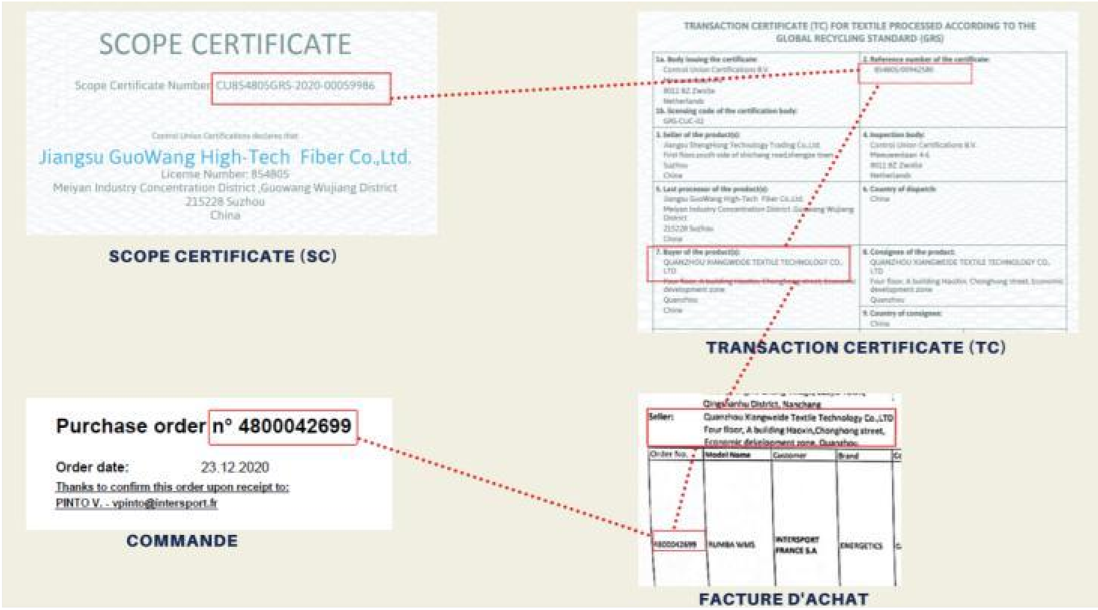
The case of Intersport is an interesting example of how companies can become concerned by environmental issues. The SQD team develops numerous fabrics for many different sports such as triathlon, swimming, training, and others. However, Intersport, similarly to all the companies outsourcing their products, faces problems on evaluating the product received. Indeed, the outsourcing of the products using suppliers in other countries can cause problem of transparency toward so-called eco products. This can create a mistrust not only from Intersport to its suppliers, but also from the customers toward Intersport.

Thus, the objectives of Intersport are plural:

- Transparency, toward consumers on products called "eco-friendly",
- Responsibility, as large companies can have an impact on the highlighting of the problems from the fabric industry,
- Traceability. Indeed, the DDPP (Direction Départementale de la Protection des Populations, translated "Population Protection Direction Department") is in France responsible for ensuring quality and safety concerning several areas such as alimentation, animal health or non-food products and services. The objective of Intersport is to prove to the authorities such as DDPP that the certified products are traceable, and the lifecycle of the product can be followed (50).

The measures taken have begun with the establishment of regulation. Several certifications are used at the moment, on recycled polyester (GRS, Global Recycled Standard) (51) and biological cotton (GOTS and OCS, respectively standing for Global Organic Textile Standard and Organic Content Standard) (52,53). These certificates establish criterions on the verification of the number of organic fabrics or recycled materials in the product.

The problem of traceability comes from the production chain, which is often longer than a direct supplier/customer relation. Indeed, there are several actors in the production chain, including the responsible for yarn, fabric, garment and often a trader if the supplier outsources the order before Intersport. Thus, it becomes necessary to ensure the traceability of the documents that can attest that the product is certificated. It can be done by verifying several documents such as Scope certificates, Transaction certificates, invoices, or orders (42).



Shape 3: Possible ways to trace the certification of a product, by Marais (2021)

The link between the images shows, from top left to bottom left, the reference of the certificate, the buyer of the certificate, and the number of the order on the products on which the certificate testify the validity on it (which is in the invoice and on the order).

These documents have the benefit of being able to be authenticated. Either by the use of a QR code on the document, or by verifying if a society is certified through a dedicated web page (54). The next step, according to Marais, would be for Intersport to make their own control on the products, by asking laboratories to verify the quality of the product, instead of relying on the certifications only.

However, these certifications are made on a small-scaled part of the product developed by Intersport. There is a lack of in-depth changes concerning the whole life cycle of the products as the certifications remain non-mandatory. Added to that, large companies deplore the absence of investments and tools in environmental projects (55).

Still, the motivation of young recruits, the growing interest through the stock market index as Dow Jones Sustainability (3) and the possible long-term results can motivate the companies, including well implemented companies such as Intersport, to work in this direction. The development of technologies centred around data gathering allows to recover useful information, and as the climate change affects the benefits of the companies (130 billion euros of loss in Europe due to weather phenomenon), It becomes all the more beneficial for companies to develop this axis (3).

iv. Regulatory requirements

As social considerations can be strongly related to environmental ones, the bicycle helmet, like every other product, must also pass tests of safety and norm regulations in order to be sold. Here is a reminder of the quality tests a bicycle helmet must pass to be sold.

According to the French ministry of economy and finance, bicycle helmets are considered as individual protection equipment (IPE) and must abide the European Parliament rules 2016/425 and council of 9 March 2016 (56). These rules define three categories of IPE, depending on the risk the absence of the product can entail:

Category 1: Designated to material protecting from minor risks for user's health. It can be superficial mechanical injury, contacts with products with low toxicity or hot temperature material (bellow 50°C). For this type of IPE, the certification might be written by the supplier himself.

Category 2: Protection against important risks. They are considered "intermediary" risks such as burn due to welding for instance. The certification at this stage can only be validated with the approval of a body empowered by that authority.

Category 3: IPE against serious and deadly risks. It can apply to protection for projection of melted metal, chemical projections, thermal issues or similar. Products of this category must be controlled every year to ensure their quality.

Bicycle helmets fall into category 2 of the safety product in the EU regulations (ref EN 1078+A1).

Moreover, several mentions are compulsory due to the regulation and the norms for this category and must be readable during the lifespan of the helmet:

The "CE" mark that certifies the compliance of the product regarding the European demand, name and address of the manufacturer, number of the norm, size (head size) and weight, year and trimester of manufacturing, designation of the model and warning mention depending on the type of helmet.

Lastly, the helmet must pass a series of physical tests to ensure its quality. These tests are various and depend strongly on the country where the regulation is applied but consist, most of the time, in a shock absorption verification. In several European countries, the helmet is dropped from a certain height between 1.5 and 2 meters, which corresponds to a speed of approximately 23 km/h. The test is done on different surfaces, flat or round, to verify if the deformation of the helmet is neglectable and if the acceleration felt by the user is limited (57).

v. Methods for evaluation of sustainable product development

Approaches for implementation of eco-design in product development

A lot of tools have been developed to facilitate eco-design. Because of the problems of definition, the plurality of the tools and the pioneering nature of eco-design, the angle of approach has become difficult to tackle. Therefore, before selecting a specific tool among the different ones available; a company has possibilities to choose the tools and approaches as follows:

- They may to choose the general approach and level of the improvement they are aiming at,

- They may choose one or more of available eco-design tools that is the best in accordance with their targeted level of improvement,

- Use the results of these tools as a basis for their product development (as we have seen that the best results in eco-design come from early implementation of eco-tools),

- Finally, they need to use life cycle assessment to verify the improvement achieved.

Approach for eco-efficiency level selection

The simplest and most logical first approach for the implementation of eco-design in product development is to focus on several parameters, for instance, toxicity, consumption of energy or water, wastes or the assembly, and try to find the most resource intensive or harmful one. The choice of the parameter allows to focus on a particular problem and can add several benefits to a product, but what can be deplored is the lack of creativity ensuing from this method, that mostly lead to superficial changes on a product more than changes on the whole production system (58).

The strategy varies a lot depending on the type of company willing to practice eco-designing (59). A multinational company such as Intersport will have lower objectives at short, medium, and long terms than a start-up which has more flexibility.

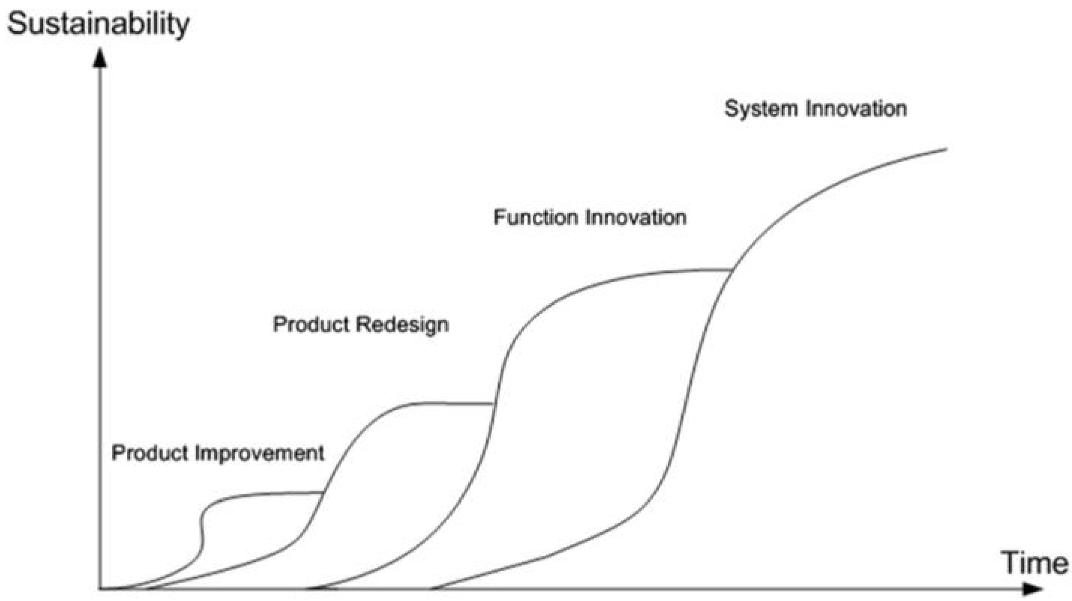
As the approach must be different according to the level of ecodevelopment wanted, Brezet (1997) listed different ranking of the environmental development approach, depending on the scope of study for which the change is done:

- Type 1: Product improvement (2-5 years). It consists in carrying out changes on a product already well developed and implemented in the market. It is the easiest method as it requires common sense more than a deep reflection for the manufacturer. Some examples are the suppression of pieces or reduction of the weight on the product.

- Type 2: Product Redesign (5-10 years). The product is re-thought to decrease its end of life. It is possible at this stage to re-evaluate the method of conception of this product and create a more disruptive version. Example: the wireless chargers of phones, which decrease the number of damaged chargers ending in trash.

- Type 3: Function Innovation (10-15 years). At this point, the product is entirely rebuilt but has to answer to the same constraints than the previous one. The idea is to restructure the product to increase in depth one or several functions. At this stage, the risks become more important in terms of costs, availability of materials or difficulty to change the habits of customers. An innovation of this type is the Seabin, a floating rubbish attached to a pump that separates water from wastes.

- Type 4: System innovation (15 years and more). This one is extremely difficult to put in place as it needs a change not only on the product but on the whole system. It necessitates the support of both customers and industrials. From this, impacting changes can be done for the society and the environment in general. For instance, the electrical hand-dryer "Airblade" of Dyson allowed to stop the use of paper, making no waste at all.



Shape 4: Four levels of Eco-design by Brezet (1997)

The previous shape represents the eco-efficiency according to the time spent, showing that the more efficient the product is, the longer it will take to set it up. Thus, type 4 innovation will be considered as the most eco-efficient product whereas type 1 innovation will have possibilities to be more developed. It is important to remind that these steps are not necessarily following each other: a company can move directly to a type 4 innovation, but it requires a consequent number of resources and can be a problem if the customers are not ready for such radical changes. Furthermore, the time scale is not fixed and can evolve depending on how the company is dedicated to this concern. In addition, it is very difficult to explore profound changes in a product since it needs to be rethought from the very early stages of development (60).

a. Tools used

From this ranking, it becomes easier to evaluate for each tool that will be described in this section which one can be adapted to the strategy of Intersport. It needs to deliver quantitative and qualitative results and consider the environmental criteria from the beginning until the end of the product development process.

These different tools can also be evaluated through the different existing norms or through eco-efficiency indicators. But it remains difficult to quantify the benefits of an eco-designed product. The use of a timeframe based on three principles was explored (61) : Resource and value, consideration of environmental, societal, economical aspects, and life cycle. From these, performance indicators can be chosen accordingly to their product sustainability contribution. As this method necessitates more knowledge of all the aspects of the development of eco-tools, the evaluation of the tools remain more pertinent with the ranking made by Brezet, which has the benefit of being clear enough without unnecessary details on its evaluation.

The selection of the different tools is difficult to establish, due to the plurality of the options and the difficulty to create categories of tools. The ones selected need to be easy to approach. They must be explicit, not necessarily easy to put in place but can provide results in a short time, which is the type of tools that would serve the interests of Intersport. Even if some of them would work better with a stronger expertise, the present cross-functional teams at Intersport allow to work on a large spectrum of answers developed through their creativity. Moreover, they need to serve as a support for idea generation, similarly to methods already used in the company such as brainstorming or benchmarking. Indeed, O'Hare (2010) highlights the importance of selecting methods close to already existing methods to be more easily accepted and used. The following of the study will depict the different tools for eco-design potentially answering to the needs of Intersport.

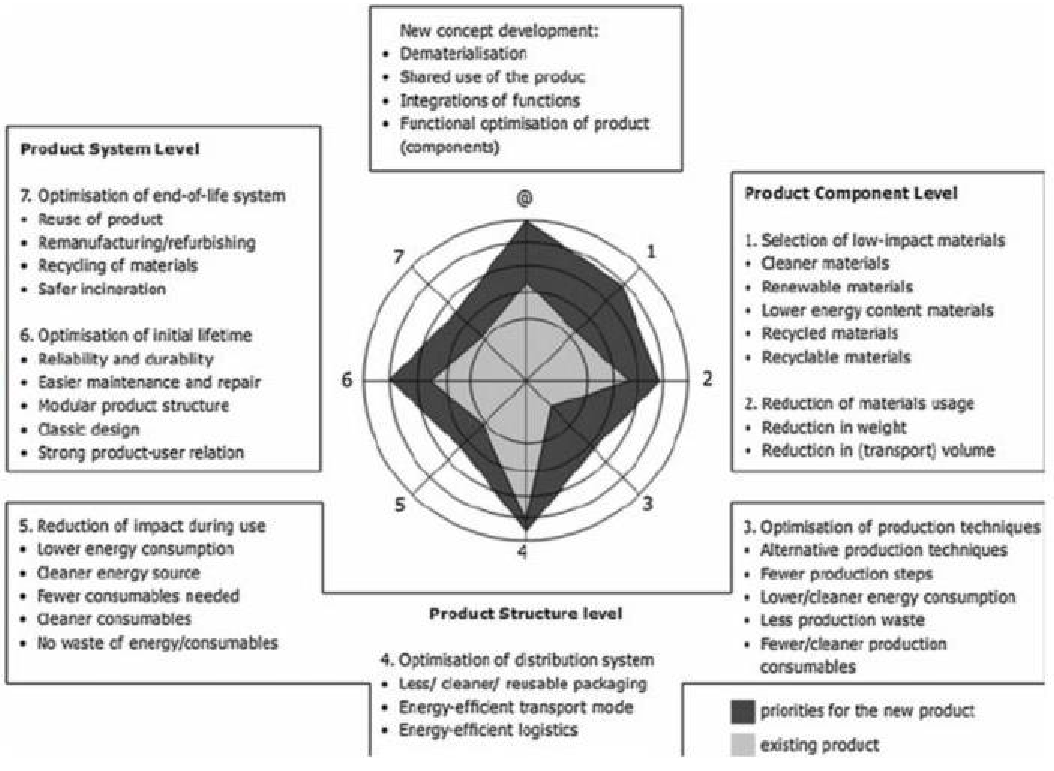
b. LiDS Wheel

One of the fundamental yet complete methodology to evaluate the different parameters to consider in eco-design is the Lifecycle Design Strategies wheel (LiDS wheel) developed by Brezet & Van Hemel in 1997. This tool highlights the importance of keeping the original product development process as intact as possible when developing a process for an eco-designed product. This system allows to identify the product, communicate on its impacts, and organize the possible solutions and alternatives with low time and efforts. The wheel, shown below, classifies in groups a selection of eight different strategies, which are:

- Selection of materials of low impact,
- Reduction of the quantity of material used,

- Selection of environmentally friendly production techniques,
- Selection of environmentally friendly distribution systems,
- Reduction of the environmental impact in the use stage,
- Optimization of the life cycle,
- Optimization of the end-of-life phase,
- New concepts and products.

The grading for each category allows to set up the priorities for the new product developed and know exactly in which area the product has the highest negative impact and so which area to work on.



Shape 5: The LiDS Wheel (Brezet and Van Hemel 1997)

c. MET matrix

Similarly, to the LiDS wheel, Brezet and Van Hemel developed a tool more focusing on the flows during production, which is the Material Energy Toxicity (MET) matrix. The latter is a 3*3 matrix divided in Material, Energy and Toxicity by line and Production, Use and Disposal in columns to estimate the impacts of each stage of production. Indeed, there are different possible environmental issues that may be considered when the companies show environmental concerns: global warming, ozone layer depletion or toxicity for instance. The choice of the division between material, energy and toxicity relies on the necessity to simplify the grouping of the different environmental issues (62).

	PRODUCTION	USE	DISPOSAL
MATERIAL			
ENERGY			
TOXICITY			

Table 2: Representation of the MET matrix, with the blank cases to complete

The MET matrix provides qualitative options at all stages of the production. It is a famous tool used by experts on the project but has the problem of relying on them mostly, which means a usability limited to experts almost exclusively.

The LiDS wheel, mixed with the MET matrix, allows to compare the possible environmental improvements by clarifying the different information on the product, which are considering the materials, the energy used, and the toxicity induced at 3 stages of the lifecycle of the product: Production, use and disposal. It is a basic tool, but it allows to have the clearest understandings of what strategy will be considered later during the product development (62).

An approach to substitute the MET matrix has been developed: the ESQCV (translated “simplified and qualitative study of the life cycle”) approach. It proposes an in-depth procedure for each of the issues linked to the product development by selecting the main environmental issues and for each of them, evaluate qualitatively and quantitatively their impact in each phase of the product development (34).

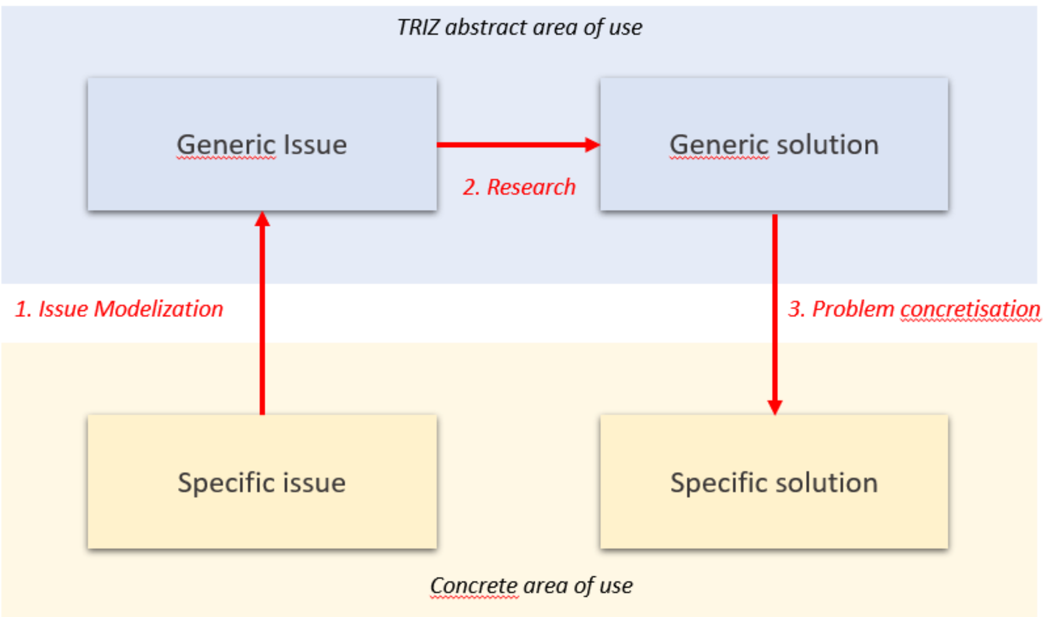
The interest of these methods is to exploit the creativity of the product developers concomitantly with the axis of eco-design. The main pitfall being, similarly to the MET matrix, the necessity of research in amount. Thus, it needs a specialized team in the area concerned to select the right parameters and not misinterpret the results due to an oversight in the elements taken into account in the scope of study (59).

Basically, these first few elements for eco-design developed are ideal for changes in the functionality of the product. It allows to generate numerous ideas but struggles to transform these ideas into technical solutions. Indeed, these different tools allow to evaluate which part of the product development process is the costliest in resources. Howbeit, it does not help to understand how to transform these parts into something valuable. Thus, they can be at the origin of fundamental changes (Type 3 and 4) but need to be crossed with other more technical tools to help for idea generation (62).

d. TRIZ Method, TRIZ matrix

Another method which has been developed and appropriated by different users is the TRIZ method. TRIZ, meaning Theory of Inventive Problem Solving, is a theory developed by Altshuller (1946) whose purpose is to codify and elaborate laws that an innovative product will follow, which will tend to make the creation process more foreseeable. This way, it is possible to lean on solutions that were found on other problems that will be possible to adapt to our case. This method is a rational approach and differs from creative ideation process such as brainstorming, which depends more on the prior knowledge of each member. It rests on a mechanism in four steps (63) :

1. Identifying the problem that need to be solved,
2. Using the TRIZ toolbox to find the similar general problem,
3. Use the general solutions found,
4. Adapt these solutions to the specific problem.



Shape 6: Representation of the TRIZ method

The necessity of abstraction of the problem allows to construct a general issue in the form of a contradiction with the first assumptions. This way, a general problem allows to benefit from solutions that are used outside the area in which the initial problem is developed (64). These contradictions can be technical, physical, or operational and once the problem that needs to be solved is recognized, it will be linked to a parameter to improve through different tools.

Indeed, numerous tools have been developed after the TRIZ method: The Evolution law (Russo and Regazzoni, 2008), 9 screens (O'Hare, 2010), the TRIZ matrix (Chen and Liu, 2001) or Case Based Reasoning method (Yang and al., 2011). Their common point is the global product approach, on how to implement technical solutions in the product through idea generation.

The TRIZ method offers many ideas but suffers from the disparity in the tools developed through this method: They are not equal in the ideas they can bring. Some of them are too focused on the technical aspects of the product development and may lack of recoil when there is a need to see the big picture, whereas some have a more global approach, such as the 9-screen approach.

Thus, one of the interesting tools that were developed according to the TRIZ method is the TRIZ matrix. The TRIZ matrix is a matrix with 39 lines and 39 columns, with the same parameter on the number of the line associated to the same number of the column: which means that the parameter of line 1 is the same as the parameter of column 1. As the principle of the TRIZ method is to come to a contradiction that will be solved, the user needs to find the contradiction ensuing from the problem of the creation of its product that will lead to the selection of 1 parameter to improve and 1 parameter to preserve among the 39 parameters of the matrix. These parameters are listed in the appendix 1.

The parameters are represented in a matrix, by columns (parameter to improve) and lines (parameters to preserve) and allow us to find the appropriate solution linked with the parameters to improve and preserve. This generic solution then needs to be transformed into our specific solution by a work of reflection made by the user of the matrix.

		Characteristic to improve				
		1.	…	14. Resistance	…	39.
Characteristic to preserve	1.					
	…					
	7. Volume of stationary object			**Generic Solution**		
	8.					
	…					
	39.					

Table 3: Representation of the matrix of contradiction, with the selected characteristics for our case

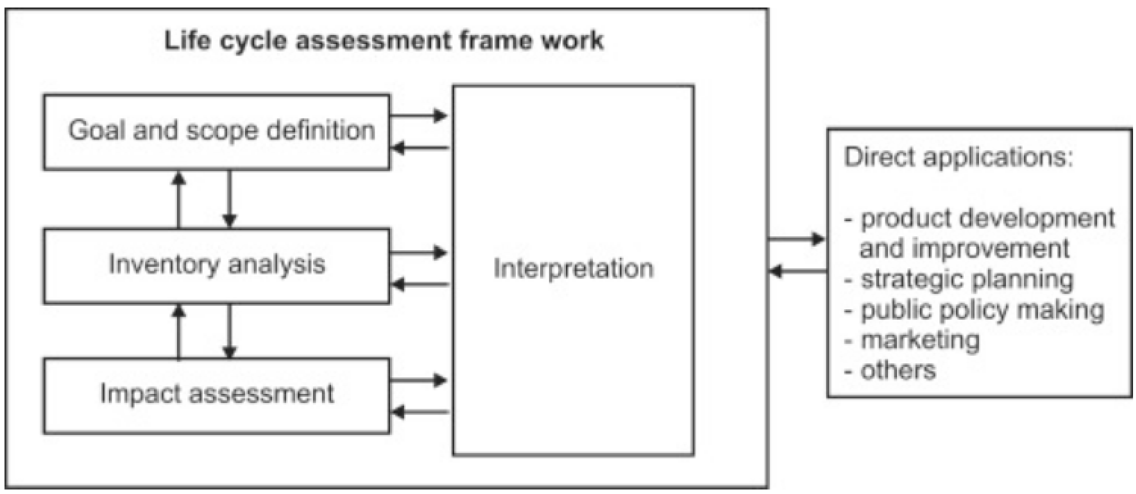
The interest of this matrix is the selection of precise criteria that leads to a certain amount of possible generic solutions. Even if the solutions given are limited, because it relies on already existing solutions, it allows the users to have a scope of study and let him use his creation process to transfer the generic idea given by the matrix into a specific solution. The selection of the characteristics to improve and to preserve will allow to know the direction to follow for the creation of an eco-designed product.

Based on the TRIZ method, another idea has been developed and called the ASIT tool (65), which is based on a process of targeting the area to improve, similarly to what can be seen with an LiDS Wheel, but also brings questions broad enough to allow ideation from the participants. This tool was adapted into the EcoASIT tool by Tyl (2012) and falls within a logic of consumption reduction. This tool, contrarily to brainstorming, aims to develop few but precise solutions. The benefits come from the easiness to generate ideas even for a non-initiate group, which is the main objective of the tool developed by Tyl (2012).

Most of these tools are developed to generate the problem which needs to be answered by the product. Besides, they are either very technical or global, which makes their use difficult if they are not directed toward the right user.

e. Life Cycle Assessment

Approaches that rely on more technical aspects of the eco-design of a product have been explored by eco-design experts. The most well-known approach is the analysis of Life Cycle Assessment (LCA). The life cycle being the history of the product, from cradle to grave, LCA can be defined as "a methodological framework for estimating and assessing the environmental impacts attributable to the life cycle of a product" (66). It is a cradle-to-grave or cradle-to-cradle analysis technique to assess environmental impacts associated with all the stages of a product's life, which is from raw material extraction through materials processing, manufacture, distribution, and use.



Shape 7: Stages of an LCA according to ISO 14040

From its definition, it is possible to divide the LCA process in four steps (67) :

- Definition of the scope of study: What will be the elements and the results needed to compare the products. The system unit needs to be defined at this moment since it will have repercussions on the rest of the study. For instance, a product needs to be decomposed in its different components to differentiate the impact of each one without dependency on the influence of other components.

- Gathering of the information on the different flows. They can be material, energy or transport mainly, but can be extended to other sources of information if they are already known.

- Calculation of the impact for each of these flows, which can be toxicity, CO_2 emissions, water consumption or energy used for the main ones. This is the calculation part where several informatic tools can be used. The use of these software allows quantitative information but necessities a lot of inputs on the whole life cycle of the product, which are not necessarily easy information to obtain.

- Interpretation of these calculations. It can be done by comparison between the calculation of the impact of an eco-designed product and a classical product for instance.

The LiDS wheel and LCA can be used in parallel with a MET matrix. Since the life cycle analysis represents an important part in the evaluation of the eco-design of the product, a MET matrix would help to be more exhaustive on the different values and flows that must be considered in the third step of the LCA and among the categories of the LiDS wheel.

As explained in the third step, the problem of this strategy is that it requires a large amount of data before the calculations, and the results depend strongly on these inputs and their precision. This tool is mostly usable for experts in the material used in order to deliver precise data. However, it is a beneficial tool for the evaluation of the environmental impact. Because of the factual results that the LCA method provides, it can be evaluated as a low stage eco-designing tool according to the innovation type evaluation by Brezet. Indeed, it provides several information on the material, but remains centred around a technical approach, which only offers solutions such as material changes. Its purpose remains mostly the evaluation of an already established product.

f. Current approach at Intersport: Benchmark

For the moment, eco-design methods used at Intersport are limited. One of the main methods currently used is benchmarking. Benchmarking is a continuous analysis of products from competitors to help increasing the performances (68).

The purpose is to find on the sporting goods market eco-designed products that seem possible to develop by our side. After evaluating the feasibility of the product, the SQD service launch a call for tender to different suppliers and ask for a proposition, Minimum Ordered Quantity (MOQ) and a target price.

Shape 8: Call for tender for a skateboard, sent to several suppliers

The interest of this method is its ability to ensure products that have already proven to work, since they are close to products already sold by competitors. However, the eco-designing creativity process is very limited by benchmarking: the proposition of the supplier can be subject to modifications, but since the supplier must propose a product close to the one selected after the benchmark while being sure to avoid problems of patents, it limits his possibilities.

The possibilities of designing the products from Intersport side is mostly on the fabric since it is a strength of the SQD service. Thus, bags and clothing are almost the only product that can be worked before production entirely from the service without passing by other suppliers.

This method highlights the importance from Intersport to be quick in the development of products. It is given approximately three weeks to one month for the suppliers to give a proposition and begin to work on the products. This must be taken into consideration when the choice of the tools used for eco-design will be done.

3. Conclusion on the eco-design consideration in product development in the case of Intersport

To respond to the demand concerning eco-design and develop a truly new concept, the problem must be taken in the big picture: It must be though at early stage and considering not only the product as a specific answer to a need but a material that would potentially answer other issues, since the product design depends strongly on the function it has (56). This induces a necessity to focus not only on the product but also the context in which it is used.

Through the description of the different tools for eco-design, it has been possible to highlight the numerous problems encountered when it comes to developing an eco-designed product: The limits of creativity, technical aspect, or the difficulties to evaluate the interest of a method depending on the users. Still, it has been shown that their use allows, according to their type, to find solutions that can be technical, mostly for the tools accessible by experts, or general, more centred around creativity of the teams. These different solutions can originate products that can be innovative and less polluting, but to induce a fundamental improvement in the consumption of the eco-designed products, the innovation thinking must be done considering the product in its whole, with all the economic, cultural, and sociological context (Benjamin Tyl, 2011), which implies the company, but also the customer's state of mind.

At Intersport, the idea generation process comes a lot from the designing part, but it considers the economic aspects mostly. Indeed, the approach of Intersport toward their own brand is to be inspired by products already implemented in the market, at a preferential cost. It is a problem since considering the environmental aspects could at the same time allows benefits to the brand and enhances their sympathy capital among customers. Added to that, weighty companies such as Intersport can directly use their notoriety to impact the customers ideas and implement new ways of consumptions, but also need to be efficient in the choice of the developed product. Therefore, the choice of the tools must be based on quickness of execution and easiness of understanding to be applicable at large scale among the company.

III. Method Section

This section will depict the process followed for the choice and evaluation of the environmental impacts of different helmets and their presentation to the SQD team of Intersport. Firstly, a collection of information will be made on the bicycle helmets already sold by Intersport to know the process of manufacture and the components. From that, it will be possible to make a screening of the materials and structures used for assessing the environmental impacts of the helmets, knowing the limits of Intersport toward the environmental considerations among other constraints. Then, there will be a selection of the tool among the ones presented, and it will be explained in detail to understand how its use can contribute to finding an adapted way to develop an eco-design product. After that, the helmets considered will be decomposed into their different components considered and a LCA will be done on them to evaluate and compare their environmental impact. Finally, the presentation of the results obtained to the team will allow us to understand which aspect of this process can be understood and applied in the company.

1. Technical decomposition of bicycle helmets

Based on the literature and the explanations from the suppliers of Intersport, a standard helmet can be decomposed into three main parts:

Part	Description	Picture
Shell	Protects the inner parts from environmental influence and gives a better visual outlook	
Liner	Manages the energy during the crash	

Straps and Pads	Allows to maintain the helmet in place and add comfort	

Table 4: Composition of a helmet

Currently, many researches are made on the development of innovative bicycle helmets, especially from the environmental perspective (69). The objective will be to detail the different parts of the helmet and their composition to make a screening on the materials that will be evaluated through the LCA.

Moreover, an overview of the different other structures available will be done to evaluate their possible implementation at Intersport as eco-designed helmets.

2. Selection of the eco-design tool

Among the eco-design tools used in the product development process, many of them help in the decision making concerning the direction taken by the development. As this decision is made in the case of my work at Intersport, several criteria for selection of the most adapted tools were considered. Those criteria are:

- The type of innovation generated, evaluated from 1 to 4 according to Brezet (1997). The highest types of innovation (type 4) can originate fundamental changes but are harder to put it place and necessitate a large amount of time and a dedicated team to the project, which is not our case. We will thus prefer **innovation of type 1 or 2.**
- Support for idea generation, since brainstorming and benchmark have shown that it does not require to be an expert in the considered field if there is an idea generation process.
- Easiness of use, as the necessity of taking time to understand the tool would be too unpalatable for the employees.

We will evaluate these tools by colors (ranked from the worst to the best):

-Red, the tool does not answer to this criterion

-Yellow, the tool answers partially to the criterion but is not perfectly adapted

-Green, the tool answer to the criterion

The tool obtaining the best results will be the one used for the creation of an eco-designed helmet. If several tools have similar results, we will use both.

3. Guidance for evaluation of the products: The use of an LCA

As explained in the selection of the material for the helmets, the LCA will be made on four helmets: A PC shell helmet (called in the following "Standard PC shell helmet"), a PVC shell helmet (called in the following "Standard PVC shell helmet"), a helmet developed using the eco-design tool selected and a carbon fiber helmet.

The LCA is conducted on the lifecycle of these four bicycle helmets, from the selection of materials to transportation and use. The considerations on the end of life will be limited to a trash throw only. The use time is assumed to be 3 years and the whole transportation processes induced by the life cycle will be limited to the final product transportation from China to France, which represents 239 963 km (82).

The information on the lifecycle of these products is retrieved mainly from the Granta Edupack database, where the CO_2 emissions and embedded energy can be easily calculated using the EcoAudit tool and complemented with literature search.

To strictly compare the impact of each material separately, the weight of the whole helmet was considered the same. Thus, it induced the following distribution of weight for all of the four helmets:

- Shell: 0,023 kg
- Liner: 0,133 kg
- Pads: 0,046 kg
- Straps: 0,015 kg

These results are based on a prior group work at Aalto University were the "standard PC shell helmet" was decomposed to weight each component.

As the choice of keeping the same weight for the liner and the shell might seems odd because of the necessity to adapt the amount of material used for each helmet due to their different resistivity, it remains necessary to modify one input at a time to be able to correctly evaluate the environmental impact of each material used. If some results are non-coherent, a rework will be done on the evaluation of the amount of material used to understand if it is the cause of such results.

The evaluation of the environmental properties of the helmet will mostly focus on the carbon emissions in the following part. Indeed, the oil used in the manufacturing of plastics represents a serious concern, since plastic products represent 4 % of the European oil consumption (83). This quantity seems a low amount but represents almost 26 million tons of oil (56). Moreover, it is a representative indicator of the impact of the product, since the production of plastic also necessitates a non-neglectable amount of water consumption (57). This way, decreasing the amount of carbon emitted by the product induces several benefits in other areas such as water consumption or energy embedded for the extraction of the material.

4. Presentation of the results to Intersport

This presentation will be done in two times. In order to validate the feasibility of the project at Intersport, the process will be in a first time explained to the manager of the SQD team and my direct manager (two persons) to understand the eco-design tool used, the LCA process and how I achieved the idea of the eco-design helmet found. After corrections from them, there will be a second presentation to the whole team. The economical aspect being preponderant in the case of a big company such as Intersport, the additional cost, and other parameters such as the production Leadtime for an eco-designed helmet will be evaluated through the help of the suppliers contacted.

The organization of the presentation will be done in the following way: First, there will be a presentation of the eco-design concepts: What is eco-design, the differences with circular economy and notable examples. Then, I will explain the different tools of my thesis, including the eco-design tool used and the LCA software. I will then explain how it conducted me to the creation of a liner with a mix of EPS and cork for a bicycle helmet. Finally, I will present the benefits of using such tools for the team.

The purpose of this presentation will be at first to make the team aware of the challenges of eco-conception and that there are tools available to implement eco-design in the product development process. If the results are conclusive, the next step will be to systematize the use of the eco-design tool in the product development process.

IV. Results and Discussion

1. Materials and structures available

i. External shell materials and production methods

The external shell is, for most of the helmet, either made in ABS (Acrylonitrile butadiene styrene), PC (polycarbonate), PET (Polyethylene terephthalate), PVC (polyvinylchloride) or in carbon fiber.

The ABS is a thermoplastic polymer, which means that its form can be modulated at a certain temperature and solidified when it is cooled down. This polymer is preferred for heavier protections. Indeed, the combination of the three motifs in the molecule allows a high impact, scratch and heat resistance while remaining affordable at low price compared to PC shells (70).

These two materials are both well resistant to impacts, high temperatures, to chemical degradation and they are easy to recycle. However, the PC shells are lighter, relatively easier to manufacture as it is transparent and can easily be coloured. Its features are for the large majority better than ABS but at the cost of higher expenses and inability to withstand scratches (71).

PET is a lower quality plastic used, among other things, for the manufacturing of plastic bottles. According to ©Plastisem, it has a lower ability to withstand high temperatures than ABS or PC, with a glass transition temperature of 70°C. In counterpart, it is much cheaper than the two materials quoted earlier. This is the reason for which this material is used for basic models.

The process of manufacture for helmets with a PET shell is the most basic one: The external shell is glued on the liner and joined on the boundaries with adhesive. This process is called glue-on or tape-on. The main issue of this process is that a thin space is not fulfilled between the liner and the shell, and as the liner is not stable, the durability of the helmet deceases compared with other processes of manufacturing.

Shape 9: Adhesive on a kid helmet (red), Intersport France website

Concerning PVC, the material is close to PET and uses the same processes of manufacture, the result being mainly aesthetic and mechanical (PVC is slightly stronger than PET).

Finally, the carbon fiber helmets are the only helmets created by a chemical process called polymerization, from molecules of polyacrylonitrile. The fibers obtained are woven, and linked with a thermoplastic resin (72).

Shape 10: PVC shell (left) and PET shell (right), Intersport website

The manufacturing process associated to ABS is the moulding process, which will be described in the next section. Concerning the PC and PET shells, the process used is Vacuum forming.

This process is adapted to thermoplastics polymers: A sheet of thermoplastic is heated up and settled on a mould with the desired shape. A vacuum is done for the thermoplastic sheet to frame the shape accurately. Then, after a short period of cooling down, the vents in the shell are cut by hand or with the help of a machine (73).

Through the information given and verified by the different suppliers of Intersport, we will be able to limit the scope of study of the available helmets and evaluates helmets composed with these shells.

ii. <u>Liner</u>

The liner is the internal part of the helmet. It represents the largest amount of material in the helmet: around 60 % of the total mass in average (*Comparison between the product and guidance*, Oct 2020). There are two sorts of liners for recreative use: rubbery and flexible or hard and compressible. The former is destined to skateboard or hockey adherent and composed of Thermoplastic Polyurethane (TPU) or SALi (rigid alumina). We will not go further on these products as they are not adapted for the need of the bicycle users on which the study is driven. On its side, the hard and compressive liner can be made in EPU (expanded polyurethane), EPP (expanded polypropylene) or cellufoam, and most of all, EPS (expanded polystyrene). As a matter of fact, the majority of liners for bicycle helmets are made of EPS (74).

The most used process of manufacturing for the liner, and for the ABS shell, is the Injection moulding process. It consists in injecting, assembling, and unifying the different parts of the helmet in one operation, in the mould. Polystyrene marbles are disposed in the mould with an expansion agent, such as Pentane, and then pressed at high temperature with a vapor steam, allowing the marbles to expand and shape into the external shell by swelling and sticking together. A parameter which can be influenced is the density of the marbles, depending on the reaction wanted during an impact with the helmet: The helmet will be more resistant if the foam made from the marbles is dense, but the impact can be more painful. The interest of making it directly in the shell is to take the exact shape for the marbles and assemble the two main parts, the shell, and the liner, in one process. It is a quick process, but also an economic one. The main drawback comes from the inability of the marbles, once they are expanded, to come back to their original form. This induces the unicity of usage for a helmet: once it is broken, it is impossible to manufacture it again with the same marbles.

iii. Different technologies and Structural changes

The previous part showed the structure of the liner in current bicycle helmets. However, several companies explore alternatives to this structure of shell and liner by rethinking the whole helmet. This section presents the alternatives available at the moment.

a. Hövding airbag

The Hövding airbag is basically an airbag conceived for bicycle users that will swell right before the impact (75). This airbag has raised a lot of interest since it is a lot more aesthetic than current helmets, because it is placed around the neck and does not cover the head when it is not deployed. It was demonstrated that for precise values of pressure and thickness of the airbag, it can drastically decrease the injury risks of bicycle users (75).

Nevertheless, this technology has several drawbacks: It is significantly heavier than other current available helmets as it weights 800g where the other helmets scarcely exceed 300 to 400g. Even if the weight is targeted on the shoulders, this difference can be tiring for a long run. Added to that, the mechanism needs to be very precise to consider whether it needs to be deployed or not. As it is supposed to be deployed at a specific moment, it can be a problem if the user is not falling but just sliding and the airbag is deployed for no reason. Thus, there are difficult cases that need to be considered to decide if the user is having an impact and the airbag needs to be deployed or not (76).

b. Different structures

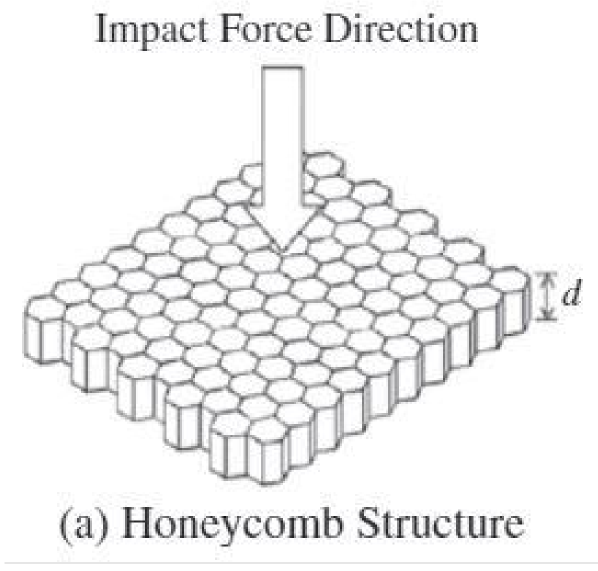
As it has been seen with the principle of the airbag, several companies have been working on the structure of the helmet itself. Among the possible structures, the honeycomb has been strongly evoked to decrease the impact forces.

Several societies, such as HEXR, decided to work on this aspect of the helmet by printing a honeycomb structure in 3D with Polyamide-11(77) :

Shape 11: Helmet from HEXR Website

This structure enables to decrease the use of foam such as EPS while conserving the safety performances. The interest of such a helmet is that it is reusable after a moderated impact, contrarily to foam liner's helmets.

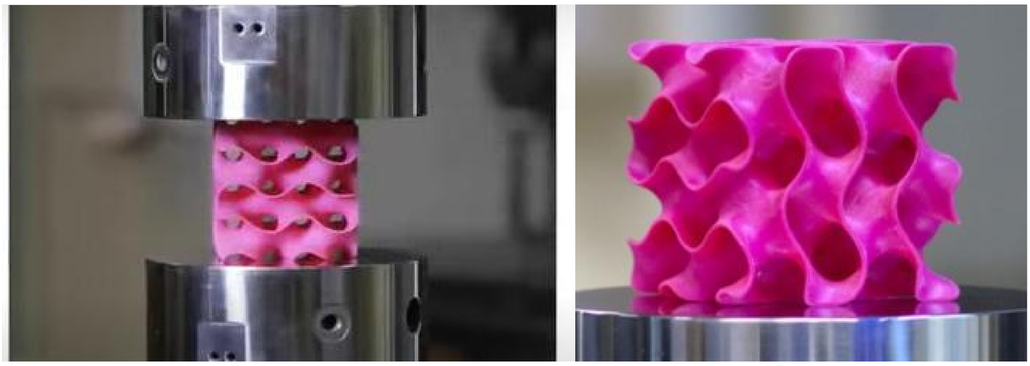
To select the best size for the honeycomb cells, an algorithm has been used to define the minimum structure that will provide a protection as good as current helmets that have been developed (78). The structure has shown to control energy delivery within a light structure, which remains beneficial since helmets needs to provide airflow and facilitate heat transfer.



Shape 12: Hexagonal structure of a honeycomb (58)

Reducing the thickness of the honeycomb makes the material more prone to bottom out, which means higher risks to reach its lowest resistive point. Broadly speaking, a trade-off must be made with the thickness of the honeycomb structure since stiffer material will make the user undergo more pressure but has a higher ability to bottom up whereas flexible materials will undergo less acceleration but will reach their ability to bottom up at lower energy. To conclude, the geometry of the structure must depend on how powerful the impacts are expected: the stronger the impact will be undergone, the deeper the honeycomb must be (78).

Considering the importance of the structure, other possibilities could be developed. One structure with another geometry that could possibly be though about is the gyroid. Discovered by Alan Schoen, this structure has been applied to graphene and has shown exceptional resistance at low density, mostly thanks to the structure. The possibilities for the future of plastic structure with high strength are considering this structure (79).



Shape 13: Gyroid structure (photo from Massachusetts Institute of Technology)

Another important part of helmet research focuses on the practicability of use. Several companies such as Hedkayse or Overade develop foldable helmets able to reduce to 50 % the space used and make it possible to store it in a bag more easily (80).

Shape 14: Hedkayse website

What can be seen is that there has been several tests concerning renewable materials, natural materials or structural changes that show great results toward bicycle user’s safety. A lot of these technologies and material changes focus on the most quantitative part of the helmet, which is the liner. V.Tinard et al. (2012) pointed out the possibility to effectuate changes on the outer shell, for instance by reducing the resistance of the material in the places where the most important deformations occur in order to facilitate the dissipation of energy (81).

The structural changes made on bicycle helmets that we have seen have a disruptive purpose and try to establish a type 4 innovation on bicycle helmets. As Intersport has a lower flexibility than the startups developing these products, we will not work further on an innovative structure of the helmet.

iv. Straps ans pads

These parts of the helmet are mostly made of polypropylene or nylon. With the glue-on process, they are added to the liner before the laying of the shell whereas they are added after the process with rivets if the liner is in moulded, which prevents their degradation due to temperature. The development of magnetic buckles is also worked to allow an easier use of the helmet, although the material used for these buckles remains costly.

All these considerations on the composition of bicycle helmets will help us in the choice of the materials used for the LCA.

v. Choice of the material for the helmets evaluated

The objective is to evaluate the efficiency of the eco-design made with the help of the tool used. Thus, there will be a comparison with this eco-designed helmet, and a helmet which needs to be the most representative of the current available helmets on the market. Among the studied helmets developed by the SQD team, there is:

- 17,5 % of ABS hard shell helmets,
- 65 % of PVC shells,
- 17,5 % of PET or PC shells.

The materials used were confirmed by the suppliers of the helmets. Contrary to what was studied in the previous section, most of the helmets from Intersport are made with a PVC shell, whereas PET and PC shell are in minority. However, many references confirmed the use of PC shells for helmet at large scales because of their price, resistance and easiness in molding (84), (85). Thus, we will work on both helmets, not only to differentiate them from an environmental perspective, but also to have a broader vision of the possible helmets implemented on the market.

Moreover, there will be an evaluation of a carbon fiber shell helmet. Indeed, the material is known for being lightweight and an interesting product for industries such as automobiles, it has been thought that it necessitates a low amount of material to be manufactured (86). It becomes interesting in this sense to evaluate it. However, we have to consider that this helmet would have the same amount of material in it than the "standard helmets" to measure its environmental impact through the LCA. As we do not have elements of comparison to evaluate the true amount of material used for this helmet, we will consider that it necessitates the same amount of material as the standard helmets. This will also help to evaluate the differences in carbon emission for equal quantities.

vi. Summary of the different approaches

A summary table is dressed here for the different sustainable approaches that were developed for a bicycle helmet:

Approach	Advantages	Drawbacks
Composite plastic	Increases the mechanical properties of the helmet through sandwich structures	Use of plastics, problems of weight on the product.
Recycled plastics	Decreases the amount of use of non-renewable raw material, decreases the formation of non-degradable waste	The mechanical properties are deteriorated, making the product less protective
Alternative plastics	Uses plastics with natural origins, has a lower emission of carbon	Difficult to use at large scale and still long to decompose
Natural fiber Materials	Absence of plastics	Heavy components, harshly scalable, higher cost
Structural change	Type 4 innovation, deep changes in the approach of the product	Not enough conclusive results, impossible to implement at Intersport for the moment

Table 5: Sustainable approaches for a bicycle helmet

As we can see, many research focus on the use of recyclable plastics, even if natural fiber products are considered too, in lower proportion. However, the difficulty of recycling threatens the implementation of recycled plastic products. Thus, some companies work on other aspects of the helmet through several technologies, especially the structure. These technologies are not linked with sustainability improvement as the first goal, but they may have potential for this direction as well, that will not be studied for the reasons evoked previously in the method section.

The different alternatives evaluated for the moment are the recycling of plastics, the use of airbags and structural changes to decrease the amount of material used. Howbeit, many of these solutions have found limits in the price of the processes used, or because they are still under research. The solutions that will be offered by the eco-design tool needs to focus on a solution that maintains an acceptable price limit while being usable for Intersport. It will become necessary from then to select the most adapted tool based on considerations of understandability, easiness of use and types of results.

2. Outcome of the eco-design tool

i. Results of the selection of the tool used

According to the criteria used for evaluation, several tools of eco-design were considered interesting for our case. Here are the results of the applicability of each of them:

Eco-design Tool	Type of innovation generated (1=small improvement/short term; 4= high improvement/long term)	Support for Idea generation	Easiness of use
LiDS Wheel	2	X (weak)	X
MET Matrix	1	X (weak)	X
TRIZ Method	2 - 3	X	X
Ten Golden Rules	4	X	
PIT Diagram	2 - 3	X (weak)	
Eco Compass	2		X

Table 6: Pros and cons of each tool considered

As the table shows us, even if all these tools are used for eco-design purposes, they do not offer the same solutions.

The LiDS Wheel and MET Matrix work on a similar principle. They are tools which allow us to understand which aspect of product development can be worked on. However, the LiDS Wheel develops more the aspect of re-conception, which leads to higher types of innovations developed whereas the MET Matrix is closer to the idea of an LCA. Moreover, they are general methods and can be used for the development of products for companies which are especially focusing on a specific aspect of it. In the case of Intersport, the importance is for the moment to begin a work of awareness on the necessity of eco-design. Indeed, Intersport France is a cooperative that works together alongside adherents that proposes products, which can be bought or not by the adherent. The cooperative represents more than 5500 stores allocated in 66 countries (85). It induces expectations toward customers and thus a lower flexibility. In both cases, the support for idea generation is quite poor, which makes us push aside these tools.

Tools available for eco-design such as PIT diagram (Jones et al., 2003), the Eco-compass (Fussier et al., 1996) or the Ten Golden Rules (Luttrop et al., 2006), also have their specificities but they were not developed in the literature review for different reasons: Either they have a low ability to help the generation of ideas or concepts (PIT diagram and Eco-Compass) or they are too sophisticated to be used for the purpose of a company. The Ten Golden Rules for instance are divided into ten different steps in order to rethink the product. The results of the evaluation of these tools confirms our choice of not having developed them any further. Still, this last method could be useful for an in-depth change of the product for a team composed of experts in this field.

In our following case study, the angle of approach for bicycle helmets is even more difficult since it is a product that has been used for many decades (87). The product has been rethought many times and despite the use of plastic in many of the helmet seen previously, it has shown to be a reliable source of safety. It becomes in this sense pointless to rethink the whole functionality if the principal objective of the product developed is to protect the users. It is especially difficult in a company like Intersport where most of the made products need to answer to a need, and innovative technologies have these particularities that they create themselves the need. Therefore, type 1 or 2 tools are more adapted to the needs of Intersport. The TRIZ method has the particularity to be axed around technical aspects of the product, which can be seen as a pitfall, but in the case of Intersport, has proved to be in accordance with their approach. Indeed, The TRIZ method originates several tools for answering technical innovation issues. The purpose of the following work is to see if these tools can be applied for ecological purposes.

Among these tools, the TRIZ Matrix seems to be the most exploitable one, as it englobes all the principles of the TRIZ method: An abstraction of the issue, a general solution linked to this issue, and a concretization phase to find the appropriate solution. This way, the TRIZ Matrix will be at the center of our approach for the development of the helmet.

ii. <u>Results of the matrix</u>

The first observation that can be drawn from the 39 principles exploited by the matrix is that there is no specific principle centered around eco-design or environmental consideration. Howbeit, this matrix is supposed to help to solve innovation problems, and eco-design can be seen as an innovative constraint. The work here is to “translate” the eco-design problem into a contradiction than can be solved by the matrix. Thus, we need to select the parameters from the matrix that would fit best with our necessity of eco-design.

From our needs in the eco-designed product emerge a contradiction: There is a necessity to reduce the amount of material for ecological reasons, but safety becomes at stake when the amount of material used decreases. What remains to do is to find the parameters to improve that will help our necessity to implement eco-design considerations, and the parameter to preserve that will prevent the problems of safety.

Based on the possible characteristics, we will focus on the reduction of material used and try to decrease the amount of plastic generated by the production of the product, which would also benefit its mobility. For that, we will consider that among the 39 parameters, we want to decrease either the parameters 5,8 or 16 which are respectively surface, volume and durability of the product. Indeed, improving the parameter “surface” means here that the surface will be decreased. By decreasing the surface, one of the outcomes is the decreasing of material used. This works the same with the parameter “volume”. The improvement of these parameters will directly influence the amount of material necessary and thus the plastic used and manufactured, which is our lead for enhancing sustainable considerations on the helmet. Finally, the parameter “durability” is directly related to the lifespan of the helmet. The parameter that must be kept is the parameter 7 which is the “resistance” of the product, to ensure the safety of the user.

By crossing the parameter to improve n°7: "Resistance" with the parameters n°5, 8 and 16 in the matrix, we have the following results given by the TRIZ matrix:

Parameters to improve :	**Surface**	**Volume**	**Durability**
Parameter to preserve: **Resistance**	- Local quality: Consider the different functions of each part of the helmet to improve them separately to see if they individually can have their surface reduced - Dynamics: Finds optimal conditions of use of the product - Curvature and sphericality: Replace linear parts by curves - Composite materials	- Preliminary anti-action: Prevent the negative impacts of an action by an anti-action in amount - Curvature and sphericality - Dynamics - Nested doll: Place the product inside another - Another dimension: Move the object in a 2-dimensional or 3-dimensional space	- Local quality - Preliminary Action: Gain time for an action required later during the use

Table 7: General solution

The different solutions highlighted by the matrix can be interesting subjects for further research on the development of innovative bicycle helmets. However, some of them do not help from an environmental point of view. For instance, the idea of "another dimension" in volume improvement can originate ideas such as a compact helmet that would be foldable, but this product would not help to improve the sustainability aspect of a bicycle helmet. Similarly, curvature and sphericality, dynamics and preliminary action are either unusable solutions, or not helping from an environmental point of view.

The remaining solutions are the local quality and the use of composite materials. Both solutions can bring value to environmental considerations of the helmet. The former allows us to consider each part of the helmet individually, and the latter leads to the research of materials that would still answer the security norms while producing less plastics.

The composite materials option is interesting for many reasons. But firstly, we need to define a composite: It is a material composed of an upper layer (reinforcement) that can be organic, which purpose is to resist to traction, and a matrix, which transmits the efforts and ensure the cohesion of the whole (88). One of the main problems is its difficulties to repair. However, it is light, resistant and cushions the chocks. The interface between the two materials needs to ensure the compatibility between them. This result obtained by the matrix through the parameters given is, in this sense, not really surprising as the composites have the ability to mix at the same time different characteristics in one structure but remains important. Indeed, the tool would be used by non-expert in eco-design that would probably not think about this possibility by themselves.

One possibility among composites that has been studied is the use of a helmet made from expanded cork with the matrix in epoxy resin and reinforcement made of cork (89). Not only is it a natural fiber material, but the manufacturing process relies on a simple technique called Hand lay-up technique, with a silicon mold, which makes it a usable technique at a large scale (90).

Still, one of the problems that immediately comes with the use of materials other than EPS for the liner is the density of cork, which is way higher than the one of EPS (293 kg/m3 against 120 kg/m) (91). However, by selecting a well-balanced amount of cork and EPS and a well-adapted structure, it becomes possible to use helmets as resistant as the one available currently on the market without losing too much of its lightness. In the experiments conducted by R.M. Coelho (2013), the cork used is micro-agglomerated, similarly to what is used for wine bottles. It gives anisotropic reactions for the helmet.

The results given by the study of Coelho offers several possibilities, depending on what needs to be highlighted. If the material needs to support great acceleration, sequential disposition of cork and EPS can be used whereas parallel configuration is best for decreasing the thickness of the whole helmet.

The limit of 30 % of composition made of cork was established since the weight of the helmet becomes incompatible with customer regular use passed this point (beyond 2kg). Moreover, this material can be used for its ability to recover after a first impact, which extends its lifespan compared to a more classical helmet.

Shape 15: Helmet with composite liner made of cork from the brand Bollé (108)

Finally, the considerations on the improvements on straps and pads are omitted here, as an hypothesis. This hypothesis will be verified or not during the life cycle assessment.

iii. Limits of the TRIZ Method and the other eco-design tools in general

The results obtained through the TRIZ matrix needs, however, to be put into perspective. The methods suitable for a quick solution to eco-designing such as the TRIZ matrix show that most of the time, changes performed are axed around material or the manufacturing machines. What follows this problem is that the current implementation of eco-design in product development are superficial evolution and cannot originate fundamental changes (93). Fundamental changes would need to think more about an innovative method in manufacturing and not simply consider eco-design as a parameter which would be part of the product development. But this needs a consequent amount of time whereas the development of a product is done to answer a need. In a competitive market, the time spent to develop an innovative method for eco-design could obliterate the time used to develop the actual product, causing a delay in the run with the other competitors (59).

This means the more the environmental side shall be considered, the more it needs to be worked at early stages. Indeed, the leeway decreases as much as the design process evolves (60).

The limitation of the tools developed here (LiDS wheel, MET matrix, TRIZ method and LCA) is their focus on a technological centred approach. For now, the technical aspect allows only general solutions such as the use of more eco-friendly products, which relegates these tools to type 1 or 2 innovation tools. An eco-design product should not focus entirely on the technical aspect of its production and needs to be an innovation to induce strong changes in the consumption of the product. It can be through an increasing of the social dimension of the product or the integration of the user for instance.

Moreover, a real concern coming from a techno-centred approach of eco-design is that it can induce a rebound effect, which is the increasing of consumption linked to the reduction of limits of a technology (94). These limits can be social, physical or many others. This induces a problem of compensation of the environmental benefits from a product by an overconsumption. Therefore, global consumption cannot be controlled by strategies of environmental impact limitations (95). Thus, eco-design should not focus on the product itself but all the method of consumption it implies.

Lastly, it is important to remember than the product development is guided by the consumer's demand. Many solutions for eco-designed products rely on the will of the consumer to use it. Therefore, considering the customer's first approach is paramount to help him go into the right direction (96).

3. Helmet composition

A bicycle helmet is a device used for the head protection during the use of a bicycle. Its purposes are, firstly, to reduce the risks of head injuries, but also in more specific cases to protect from the weather and allow a better aerodynamism. It envelops the upper part of the head from the top to the ears, with several variations depending on the model: Addition of a visor, LED, number of vent or other features. It can be adjusted with the straps or wheels at the back to adapt the head size. Their use has stagnated for many years but have recently been brought up to date since the increasing use of scooters for micro travels (travels between 0 and 6 km) (97).

Its purposes as a protection are plural (98): It opposes a material barrier between the head and the ground of other source of impact, spreads the forces undergone by the impact in several areas, allowing to reduce the concentration of the impact on specific points, and finally absorbs the impact energy thanks to the material used that will cushion the shock. In the following, we detail the different types of helmets considered for the study:

Helmet	Reason of the choice	Composition
PC shell helmet, EPS liner	Serves as a reference	-Polycarbonate: 23g -EPS (Expanded Polystyrene): 133g -Polypropylene: 46g -Polyester fiber (Dacron): 15g
PVC shell helmet, EPS liner	A PVC shell to evaluate the impact of the shell	-PVC (Polyvinyl Chloride) : 23g -EPS (Expanded Polystyrene): 133g -Polypropylene: 46g -Polyester fiber (Dacron): 15g
Carbon fiber shell helmet, EPS liner	A carbon shell, commonly used in current helmets, to evaluate its interest from an environmental point of view	-Epoxy carbon fiber with resin : 23g -EPS (Expanded Polystyrene): 133g -Polypropylene: 46g -Polyester fiber (Dacron): 15g
PC shell helmet, EPS and cork liner	The result of the TRIZ matrix	-Polycarbonate: 23g -EPS (70%) and Cork (30%): 133g -Polypropylene: 46g -Polyester fiber (Dacron): 15g

Table 8: List of the helmets studied in the following LCA and their composition

i. Standard PC shell helmet

For a typical helmet made of a PC shell, that is representative of the current available helmets on the market, here is the decomposition:

- **PC shell:** PC high viscosity to allow the manufacturing process of injection molding.

- **EPS:** Expanded PS foam (closed cell, 0.030): the higher the specific gravity, the higher the compressive stress, which means more energy is needed to deform the material (and higher density) at the cost of a higher rigidity, making the impact more significant. We will make a compromise here: We select an EPS which has a medium rigidity and compressive strength: the value of the specific gravity is taken at 0.030, between the maximum values of 0.020 and 0.050.

- **PP:** (rando copolymer, high flow) for the buckles.

- **Polyester fiber** (Dacron) for the straps.

Shape 16: Standard PC shell helmet from Intersport

ii. Standard PVC shell helmet

The composition of the PVC shell helmet is described here:

- **PVC:** Semi-rigid, molding and extrusion. This PVC can be easily used for consumer's goods, can be molded, and has a lower price than more rigid PVC products, which are used in the area of construction as they are denser (1,3 to 1,5 kg/m^3 against 1,3 kg/m^3 maximum for semi-rigid PVC).

- **EPS:** Expanded PS foam (closed cell, 0.030): The same EPS used in all the helmets compared.

- **PP** (rando copolymer, high flow) for the buckles.

- **Polyester fiber** (Dacron) for the straps.

Shape 17: Standard PVC shell helmet from Intersport

iii. <u>Carbon fiber helmet</u>

The composition of the carbon fiber helmet is described here:

- **EPOXY carbon fiber with resin:** The material is manufactured by the hand lay-up technic, where the resin infuses in the woven fabric according to a biaxial lay-up structure (90). This constitutes the shell of the helmet.

- **EPS:** Expanded PS foam (closed cell, 0.030): The same EPS used in all the helmets compared.

- **PP** (rando copolymer, high flow) for the buckles.

- **Polyester fiber** (Dacron) for the straps.

The only difference made with the standard helmet is in the shell, which is the part where the plastic is replaced by the mix of matrix and reinforcement.

Shape 18: Carbon fiber helmet from RNOX

iv. Cork helmet

The product by Bollé made of a mix of cork and EPS for the liner does not show many differences with the standard helmet other than the composition of the liner. Therefore, the straps, shell and buckles are the same type as the standard one.

Concerning the liner, we will use a ratio of 30 % cork, 70 % EPS as the study conducted by Coelho et al. (2013) highlights that the best results in terms of resistance were observed for this composition. This gives, in terms of dimensions, a total width of 2,5cm with a homogeneous repartition of cork inside the liner.

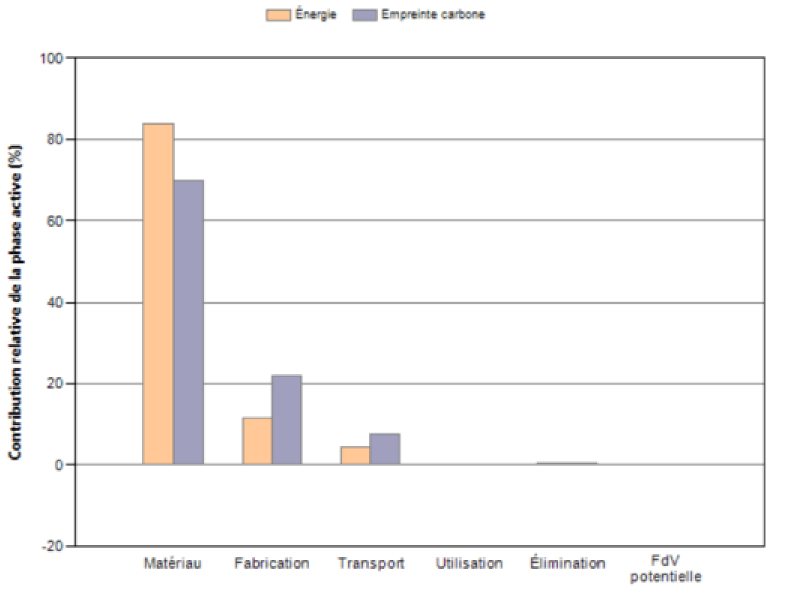
The decomposition presented in Table 4 represents a typical bicycle helmet sold by Intersport. Indeed, the difference in the helmets relies for the moment on properties such as number of vents, of foam elements or prints on it. There can be electronic device such as LED, but we will focus on the material rather than the electrical part, which is out of our scope of study.

Shape 19: Cork helmet from Bollé

4. Life Cycle Assessment results

i. PC Standard helmet

The Eco Audit tool allows us to obtain the amount of CO_2 emitted and embedded energy for all the steps of the lifecycle of the product, and by part (shell, liner, straps, and buckles). The first results obtained with the PC shell standard helmet are given below:



Shape 20: Energy consumption (yellow) and CO_2 emission (blue) contribution for each step of the product life cycle

Qté.	Nom du composant	Matériau	Teneur recyclée	Masse (kg)	Procédé primaire	Procédé secondaire	% éliminé	Fin de vie	% récupéré
1	Shell	PC (high viscosity, mol...	Vierge (0 %)	0,023	Moulage de polymère	Usinage grossier	10	Mise en décharge	0
1	Liner	Expanded PS foam (cl...	Vierge (0 %)	0,133	Extrusion de polymère		0	Mise en décharge	0
1	Pads	PP (random copolyme...	Vierge (0 %)	0,046	Moulage de polymère		0	Mise en décharge	0
1	Straps	Polyester fiber (Dacron)	Vierge (0 %)	0,015	Production textile	Coupe et rognage	0	Mise en décharge	0

Table 9: Components of the PC shell standard helmet from the software

PC shell Standard helmet	Material	Manufacturing	Transport	Total	Total (%)
Shell	0,12	0,038	0,008	0,166	18,4
Liner	0,31	0,086	0,043	0,439	48,7
Pads	0,13	0,073	0,015	0,218	24,2
Straps	0,07	0,003	0,005	0,078	8,7
Total	0,63	0,2	0,07	0,90	100

Table 10: CO_2 rejected by the PC shell standard helmet

First, we can notice than the contribution of the transport is low compared to the materials themselves: nine times less contributive. This validates our hypothesis on the absence of consideration of the trucks for transportation.

Furthermore, among the materials, the liner has confirmed to be the most important contributor of CO_2 emission: almost half of the total CO_2 emission is due to the liner only. The pads come second with 24,2%.

ii. PVC shell standard helmet

We will first compare the preliminary results obtained by the PC shell helmet with the PVC shell helmet, to evaluate if there are notable differences.

Qté.	Nom du composant	Matériau	Teneur recyclée	Masse (kg)	Procédé primaire	Procédé secondaire	% éliminé	Fin de vie	% récupéré
1	Shell	PVC (semi-rigid, moldi...	Vierge (0 %)	0,023	Moulage de polymère		10	Mise en décharge	0
1	Liner	Expanded PS foam (cl...	Vierge (0 %)	0,133	Extrusion de polymère		0	Mise en décharge	0
1	Pads	PP (random copolyme...	Vierge (0 %)	0,046	Moulage de polymère		0	Mise en décharge	0
1	Straps	Polyester fiber (Dacron)	Vierge (0 %)	0,015	Production textile	Coupe et rognage	0	Mise en décharge	0

Table 11: Components of the PVC shell standard helmet

PVC shell Standard helmet	Material	Manufacturing	Transport	Total	Total (%)
Shell	0,054	0,032	0,008	0,094	11,3
Liner	0,31	0,086	0,043	0,439	53,0
Pads	0,13	0,073	0,015	0,218	26,3
Straps	0,07	0,003	0,005	0,078	9,4
Total	0,56	0,19	0,07	0,83	100

Table 12: CO_2 rejected by the PVC shell standard helmet

As we can see, the total CO_2 emission is lower for this helmet: 0,83 kg against 0,90 kg for the PC shell helmet. As the shell is less contributive in CO_2, the part of the liner in the CO_2 emission becomes more important: 53 %. This way, it will be interesting to compare the PVC and the PC shell helmet with the cork helmet, to evaluate the gap between each other and evaluate the pertinence of the use of environmentally friendly material in the liner.

iii. Carbon fiber helmet

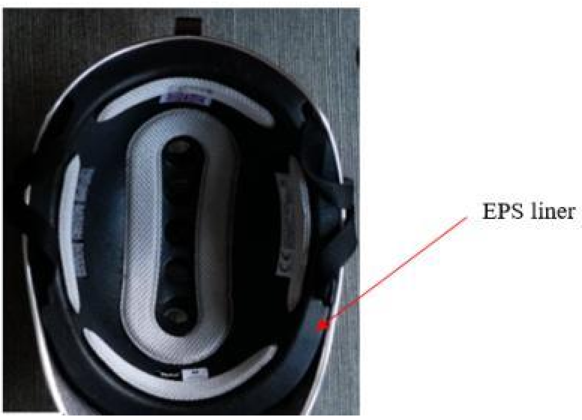
The case of carbon fiber helmets has been already explored to create highly resistant products. It is indeed lighter and stronger than plastic equivalents (72), and has the benefit of being usable several times because of its resistance to fatigue. Here are the results for this helmet:

Qté.	Nom du composant	Matériau	Teneur recyclée	Masse (kg)	Procédé primaire	Procédé secondaire	% éliminé	Fin de vie	% récupéré
1	Shell	Epoxy/HS carbon fiber, r...	Vierge (0 %)	0,023			10	Mise en décharge	0
1	Liner	Expanded PS foam (cl...	Vierge (0 %)	0,133	Extrusion de polymère		0	Mise en décharge	0
1	Pads	PP (random copolyme...	Vierge (0 %)	0,046	Moulage de polymère		0	Mise en décharge	0
1	Straps	Polyester fiber (Dacron)	Vierge (0 %)	0,015	Production textile	Coupe et rognage	0	Mise en décharge	0

Table 13: Components of the carbon fiber helmet

Carbon fiber helmet	Material	Manufacturing	Transport	Total	Total (%)
Shell	1,1	0,086	0,008	1,194	64,8
Liner	0,31	0,073	0,043	0,426	23,1
Pads	0,13	0,003	0,015	0,148	8,0
Straps	0,07	0	0,005	0,075	4,1
Total	1,61	0,16	0,07	1,84	100

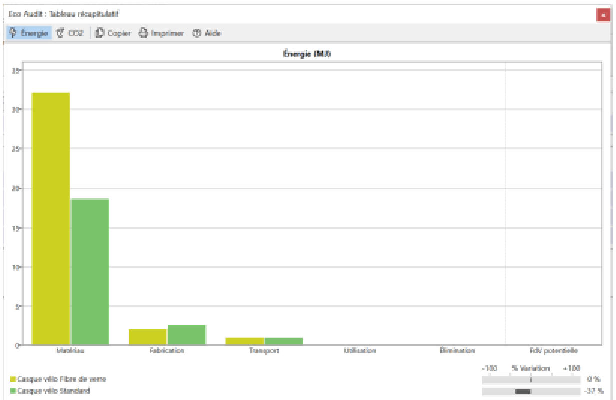
Table 14: CO_2 rejected by the carbon fiber helmet



Shape 21: Carbon fiber helmet from Dashel (99)

As previously said, the carbon fiber is used to replace PVC or PC in the shell, which represents, accordingly to tables 27 and 29, respectively 11,3 % and 18,4 % of the rejects of CO_2 in the material recovery among the different parts of the helmet. For the carbon fiber helmet, the shell has a CO_2 emission over 1,19 kg, which represents more than 64 % of the total helmet emission. Plus, the creation of a bicycle helmet with carbon glass still necessitates the use of EPS as a liner to ensure the cushioning at the impact.

Still, a comparison was made with the replacement of PC shell by a carbon fiber shell to evaluate the difference:



Shape 22: Comparison of energy consumption of carbon fiber helmet (yellow) and standard helmet (green)

As we can see in Shape 21 and through our evaluation made through the previous results, the use of carbon fiber that is a lot more demanding in energy and emits much more CO_2, especially in the material part, which makes it not an acceptable solution for our purpose. Thus, the use of a carbon fiber helmet is beneficial for high level sportsman, but it is much more polluting. The hypothesis on a possible use of a carbon fiber helmet for environmental purposes is rejected.

iv. Cork helmet

The solution given by the TRIZ matrix will be evaluated here. The partial replacement of EPS by cork was made in a way that the total weight remains equal to the PC and PVC shell helmet, to be able to compare equivalent products in terms of mass and by the same time maintain the percentage of 30 % cork and 70 % helmet. The composition and results are given below:

Qté.	Nom du composant	Matériau	Teneur recyclée	Masse (kg)	Procédé primaire	Procédé secondaire	% éliminé	Fin de vie	% récupéré
1	Shell	PC (high viscosity, mol...	Vierge (0 %)	0,023	Moulage de polymère	Usinage grossier	10	Mise en décharge	0
1	Liner 1	Expanded PS foam (cl...	Vierge (0 %)	0,0931	Extrusion de polymère		0	Mise en décharge	0
1	Pads	PP (random copolyme...	Vierge (0 %)	0,046	Moulage de polymère		0	Mise en décharge	0
1	Straps	Polyester fiber (Dacron)	Vierge (0 %)	0,015	Production textile	Coupe et rognage	0	Mise en décharge	0
1	Liner 2	Cork (low density)	Vierge (0 %)	0,039	Incl. dans la valeur matérielle	Coupe et rognage	0	Mise en décharge	0
1				0			0	Aucun	0

Table 15: Components of the cork helmet

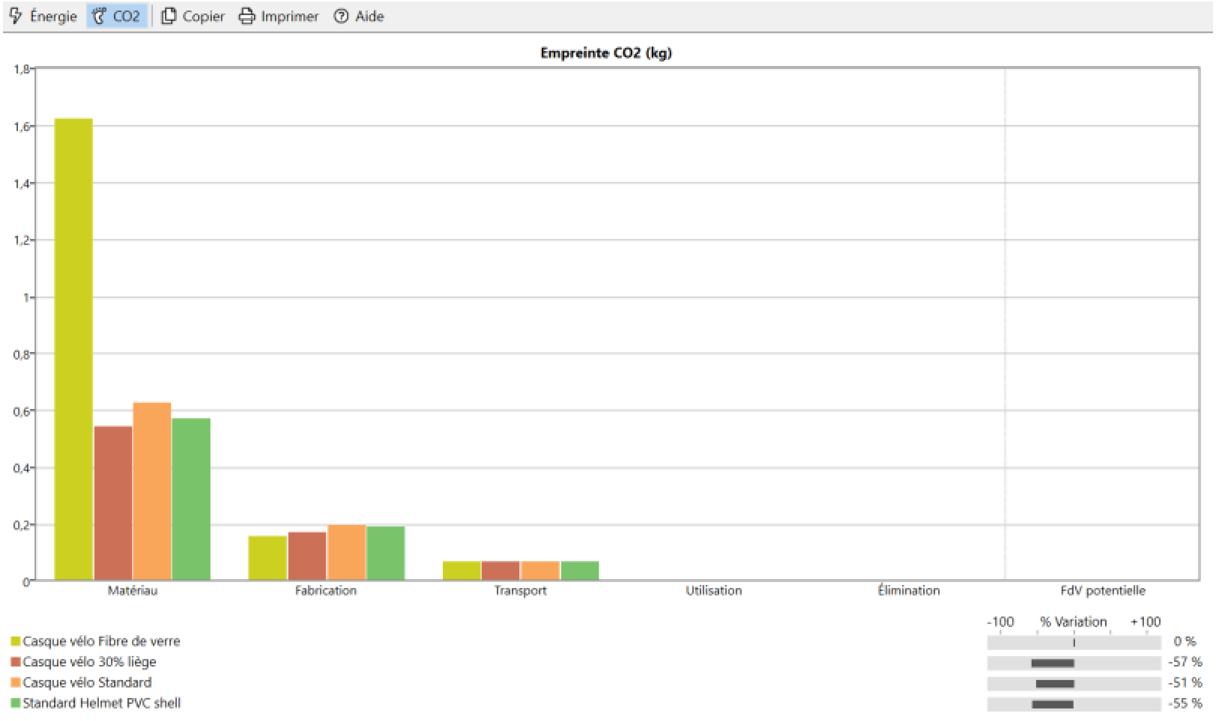
Cork helmet (30%)	Material	Manufacturing	Transport	Total	Total (%)
Shell	0,12	0,038	0,008	0,166	21,5
Liner EPS (70%)	0,22	0,06	0,03	0,31	40,2
Liner Cork (30%)	0,01	0	0,013	0,023	2,98
Pads	0,13	0,073	0,015	0,218	28,2
Straps	0,07	0,003	0,005	0,078	10,1
Total	0,54	0,17	0,06	0,77	100

Table 16: CO_2 rejected by the cork helmet

Through the results of this evaluation, we can see that the total emission of the liner in the case of the cork helmet is 0,31 + 0,023 = 0,33kg of CO_2. Which makes the total CO_2 emission of the helmet lower than the two previous helmets (PC and PVC shell).

v. Comparison of the results

The following shape represents the comparison between the four helmets evaluated:



Shape 23: Comparison in CO_2 emission for the carbon fiber helmet (green), cork helmet (red), PC shell helmet (orange) and the PVC shell helmet (green)

Besides the high CO_2 emissions of the carbon fiber helmet, the three other helmets have similar CO_2 emissions. Still, the cork helmet is the lowest of all in the material part but also in general considering all the aspects of the product lifecycle. A focus on the comparison between the PC shell and the cork helmet was made evaluate more precisely the environmental benefits between products for which the composition of the liner is the only difference:

Shape 24: CO_2 emissions comparison between the standard helmet (green) and Bollé's helmet (yellow)

We can see that there is a difference between the two helmets: with only 30 % of cork replacing the EPS, there is a decrease of over 0,085 kg of CO_2 footprint in the material itself, and a global CO_2 footprint of 0,125 kg of CO_2 considering all the stages of production.

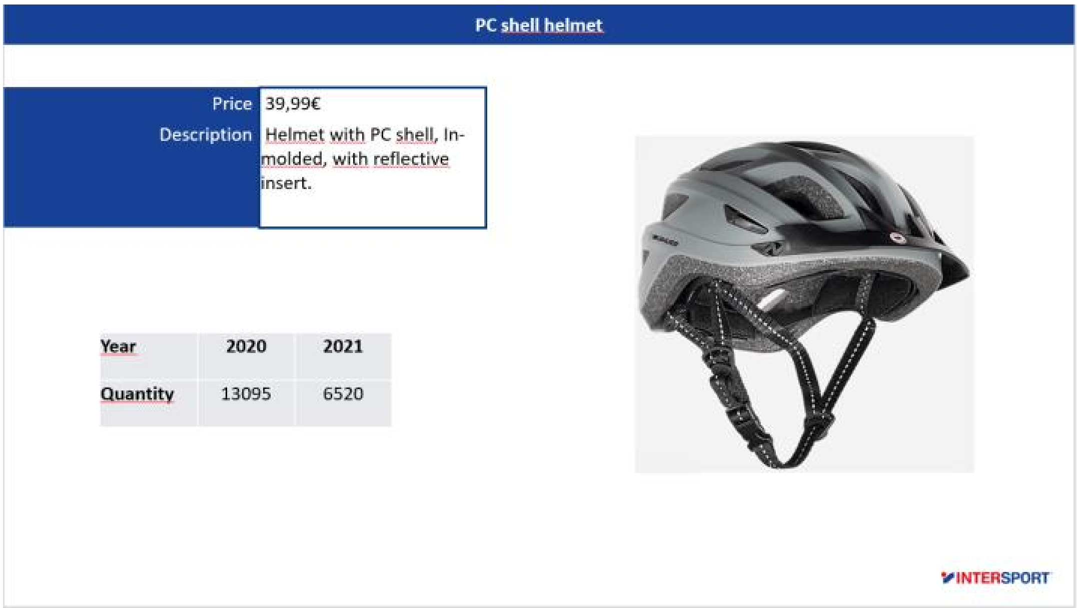
This represents a small amount of carbon emission for one helmet. But considering the orders of Intersport, which represents thousands of helmets for each model, the amount of CO_2 emission becomes much more important.

Here are the number of orders in the year 2020 and 2021 for three products made by Intersport:

– "Casque ville polyvalent", which is a helmet with a PC shell, the most representative of the model used for calculation of the CO_2 emissions in the software.

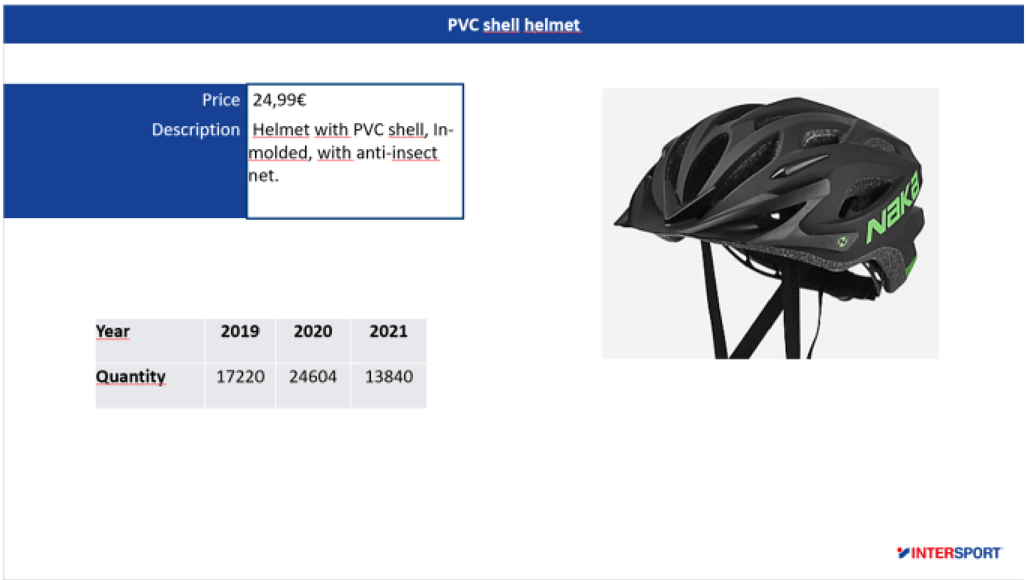
– "Casque ville LED 360", which is a high-quality product, made in lower amounts but at high costs, which could be the case of the eco-designed bicycle helmet we are planning to produce. It could give a more precise approximation of the number of helmets that would be ordered for products in a similar range of price, which is more appropriate with our eco-designed helmet.

– "Casque performance 16", which is a PVC shell helmet, represented in shape 10.



Shape 25: PC shell helmet sold over the last 2 years

Shape 26: LED helmet sold over the last 2 years



Shape 27: PVC shell helmet sold over the last 3 years

For the PC shell helmet, if we consider the lowest year in terms of order, we will focus on the year 2021 with 6520 units bought. For the LED helmet, the year 2021 was not representative because the product needed to be reordered in a large amount due to the absence of replenishment because of the covid crisis that prevented the supplier from replenishing correctly. Thus, we will consider the amount of 5 550 helmets ordered in 2020. Finally, the PVC shell helmet orders being relatively high but similar, we will make an average over these three years.

This leads us to the following results:

$CO_{2\ \text{PC shell helmet}} - CO_{2\ \text{Cork helmet}} =$ **815 kg** of CO_2
$CO_{2\ \text{LED helmet}} - CO_{2\ \text{Cork helmet}} =$ **694 kg** of CO_2
$CO_{2\ \text{PVC shell helmet}} - CO_{2\ \text{Cork helmet}} =$ **1 113 kg** of CO_2

Table 17: CO_2 emission comparisons for one year of orders of Intersport between a cork helmet, a standard helmet and a LED helmet

These results do not represent a large amount of CO_2, except for the PVC shell, as it is ordered in large quantities. For the other helmets (LED and PC shell), the average carbon footprint of a typical French is 11 tons per year. This means than its average footprint per month is higher than all the benefits that can be taken from a year of orders of Intersport of an eco-designed helmet (100).

However, these results can be analyzed from a larger scale to understand the benefits of it. As mentioned earlier, plastic is for the moment a very common resource and represents 448 million tons of production every year (101). The extension of this project to all the plastic products currently made on earth (packaging, luggage, or equipment for all types of industries) could make a significant difference with the current consumption.

vii. Supplier's information

Several information were asked to the suppliers after these results to evaluate the feasibility of the project. Here is the information that was gathered through the exchanges made:

Among the "eco-designed" helmet, what is currently on the market is:

- Recycled EPS or cork for the liner,
- Water based paintings,
- Recycled ABS for the shell or PLA compound,
- Use of soy based rilson for the buckles,
- Use of recycled Polypropylene (PP) for the straps,
- Paddings, caps and ear protection in cork, bamboo or recycled polyester.

Moreover, the price's increase due to the use of cork is evaluated around 2,5 $ by helmet. Which makes it, according to Intersport policy, an acceptable price to be developed and sold by the company. Added to that, the Leadtime of production remains similar. However, the use of a cork liner is not possible for every model of helmet: it depends on the shape, size, and components for the shell.

These results, compared with the price at which the helmets already sold by Intersport are bought, showed that developing such helmet would be possible for the company. Because of the late acquisition of these data, the results couldn't be presented to the team but only to my direct manager. The feedbacks are given in part 6.

5. Limits of the results and controversy around bicycle helmets

Among the limits of the study made, one unconsidered problem was the emission of toxic gas other than CO_2 during extraction of the oil used for plastic. Indeed, one of the main dangerous gases extracted is hydrogen sulfide, which can cause skin and breathing problems after long-term exposure, as well as the degradation of the installations of infrastructures (102). With our disposable tools, it is difficult to evaluate the amount of hydrogen sulfide released by the manufacturing of a helmet, but the use of natural fiber composites offers several advantages, including biodegradability and reduction of health risks (82),(103). Thus, natural fibers do not cause harmful gases as much as plastics, which is a benefit that we will not be able to evaluate quantitatively.

We also highlighted the ability to reuse an eco-designed helmet which has undergone crashes. But most of the helmets with a liner made at 100% of EPS are not thrown because they are not usable anymore, but because of the degradation of the EPS itself because of time due to its contact with the human contact through hair oil or cosmetics, which leads to a necessity to change the helmet approximately every 5 years (92). Therefore, it can be difficult to evaluate if the lifespan is much higher for the eco-designed helmet than for the standard PC shell helmet.

Moreover, since the very first years of its creation, the bicycle helmet has been a source of debate concerning its utility (81). Indeed, the detractors for the use of the bicycle helmets point out that most of the 2-wheels users are cautious and do not accelerate abruptly or travel at high speed. Thus, the proportion of head traumatisms due to bicycle use are not higher than those due to other methods of travelling (car, scooter, or even bare foot). Moreover, only five countries in the world have made the use of a bicycle helmet mandatory. None of the countries such as Holland or Denmark where there is the highest percentage of bicycle users are concerned. Finally, it discourages people from switching from other methods of transport to bicycle since it needs more investments.

Nevertheless, wearing a helmet has shown significant advantages for the past few decades. Despite the difficulties to establish a clear correlation between the mandatory use of helmet and its benefits because of the different cultural and social behaviours, it has been shown that it effectively protects the head during a fall or a collision, especially in dense cities, and in the cases of collisions with a motorized vehicle. Indeed, the risks of intracranial injury drop from 19,7 % to 6,3 % (82). The observation is similar for skull fractures or hematomas.

In the long run, countries such as Australia tends to show that the security is enhanced toward cyclers in countries where its practice is popular. Dorothy Robinson points out that, paradoxically, that there are all the less risks of accidents if there are more cyclists (83). This is explained by the fact that many bicycle accidents are caused by motorized vehicles, and the drivers of these vehicles are even more cautious if they are used to encounter cyclists. A city where the number of cyclists is decreased by half will see the risks of accidents rise to 52 %.

In a nutshell, the use of a helmet has proved its efficiency, but the important part of the work remains in the necessity from the governments to nudge to use more bicycles as a mean of transport. It can be achieved by campaigning on the different benefits using a bicycle instead of a car, which are as economical as environmental and beneficent for the well-being. Astonishingly, the more they will be bicycle users, the less there will be risks of accidents since motorized vehicles drivers would be more careful. This way, the benefits of a bicycle helmet will be reconsidered. Indeed, from an environmental perspective, if the product becomes unnecessary, the best solution is to suppress the product. Howbeit, for the moment, due to the low amount of bicycle users and their lack of consciousness, bicycle helmets remain useful (84). The evolution of the number of bicycle users and the regulations around it will tell how to consider the use of bicycle helmets.

6. Presentation of the project to Intersport and feedbacks

i. First presentation of the project

As developed in the method part, the presentation was firstly done to two of my direct managers. From the presentation, it has been possible to highlight the possibilities to develop adapted products for a user who is already familiar with the products of Intersport. Indeed, it becomes easier to know which part of the product can be more easily reworkable. After presenting the whole project, several points were highlighted by the managers.

TRIZ matrix: Too technical and not understandable

The presentation of the TRIZ method and how I used it were confusing for them. Not only was the understanding of the value obtained confusing since the numbers in the matrix were not explained in detail, but it didn't help them to understand how this helped me to come with the idea of the composite materials.

LCA: Economic benefits before environmental ones

One of the first problems that came out from the meeting is that the team found an interest in the decomposition of the product only from an economic point of view. In effect, one of the main benefits that came out from the meeting was the possibility to understand the price of materials and thus to be more able to bargain the price of the products from the suppliers of Intersport, whereas the objective was mostly a comparison of an eco-designed helmet and a standard helmet. The feedbacks were that it was an interesting result but as they were not as good as expected, since there is not a huge gain in CO_2 footprint emission, the benefits were mostly found on the economic side. This highlights the necessity to emphasis on the comparison between an eco-designed product and a standard one, so the principal objective of the product developed remain an objective of sustainability.

Results of the eco-designed helmet

The possibility of making an eco-designed helmet made partly of cork has been understood, but I was asked to investigate if the idea was exploitable for Intersport, and so ask to the suppliers the costs and feasibility of it, which was not done at the moment. The eco-design benefits such as the CO_2 footprint savings were not reviewed further.

However, the presentation had positive results, since it helped them to understand that I was working on eco-designing and my will to implement eco-design tools. The LCA has been seen as a useful tool for product development in general.

ii. Second presentation

A second presentation was made among the whole SQD service (22 persons) after the first feedback. The organization of the presentation was reworked after the feedbacks from the first presentation into the following (the presentation being in appendix 2):

I. Definition of eco-design and the differences with circular economy
II. The current method used by our service for the development of eco-designed products (benchmarks)
III. The existence of tools for product development (such as the TRIZ method) and their use in the case of eco-design
IV. The evaluation of the results by LCA

The feedback was the following:

TRIZ matrix: More understandable and interesting tool

The audience understood much more the TRIZ method in general than the first presentation. The struggles in the comprehension were mostly on the figures in the matrix: They had difficulties to understand how the parameters to improve and to preserve were selected, and what do the numbers in each square of the matrix correspond to. However, the idea that there are plenty of tools available for eco-conception was well established and the audience has been made aware of it. There has also been an understanding of the concepts of eco-conception and circular economy. They asked about the possibility to implement eco-conception in the process of circular economy: It allowed me to explain the possibility to link both as they have similar objectives.

LCA: Some limits highlighted

The software used for LCA were not really from the audience. Thus, it was seen as a highly beneficent tool to understand what the real origins of CO_2 emissions in a product lifecycle are. However, they highlighted that the results depended on the inputs given by the user, and thus were limited to the information I already had.

Results of the eco-designed helmet and feasibility of the project

From the eco-designed helmet perspective, there were questions on the choice of cork, and why mixing it with EPS as it is even more difficult to recycle composite materials because of the difficulty to separate cork and EPS. It allowed me to explain that my goal is to decrease the amount of plastic in general. Plus, very few helmets are recycled now, and mixing it with cork would not infringe on the process of recycling as it already necessitates to separate the different parts of the helmet, which is a long and complicated process.

Finally, the question of the cost's consideration has been tackled by all the members of the SQD team. The idea of implementing tools such as TRIZ matrix was considered possible if the results are exploitable by Intersport in terms of costings. Unfortunately, the results from the suppliers were obtained after the presentation. Because of that, I could not gather feedbacks on the feasibility of the project in our team. However, I was able to obtain the opinion of my direct manager, who explained that the project was scalable. The following of the project would be to present this idea to the bicycle category manager to ask him if we can work on the development of such helmet. He specified that with eco-designed helmets, the margin made at the resell would be high. This way, it would be economically beneficent for Intersport, in addition to the positive returns on the image of the brand.

V. Conclusion

Through this study, we have summarized the different steps of a product development process and the different solutions to optimize them. We have seen that the pre-production process, which includes screening and idea generation, must be fixed in order not to deviate far from the original objectives.

After defining eco-design to make the difference with circular economy, it has been possible to see that there have already been several tools to implement eco-design in the designing process, that can be evaluated according to the pertinency through different approaches, such as Brezet categorization among type 1 to type 4 tools. Evaluating the level of improvement possible to make by the different tools allows us to use the most adapted one to the need, which depends on the company's objectives and constraints. In our case, the choice was made on the TRIZ contradiction matrix and the life cycle assessment method, considering the former being scalable for a company such as Intersport, and the latter being beneficent for the evaluation of the pertinency of the product developed.

After reviewing the tools that were, according to our considerations, the most adapted to the needs of Intersport, the choice of the product on which the tools would be applied was made. The choice was brought on bicycle helmet, not only because of the technicity of the product, but also since it corresponds to one of the most important collection of the SQD department and improving its level of eco-efficiency would beneficiate a lot for the department, as well as many other plastic product developers, since most of the components of this product are composed of different types of plastics.

The use of the TRIZ matrix brought to the conclusion that the most interesting product to develop for Intersport would be a bicycle helmet whose liner is a composite made of a mix between EPS and cork, based on their properties and their possibility to be exploited at an industrial scale. A work was made on the shell of the helmet too, by considering a carbon fiber shell.

The results indicated that the environmental benefits were not as good as expected, even if they cause a reduction of almost a ton of CO_2 footprint emission, if we consider the whole production and orders of one model of bicycle helmet of Intersport in one year. However, the reduction of plastic used on this product could potentially be extended to other plastic products. As plastic production in the world is enormous, with more than 359 million tons in 2018, the reduction of small amounts of plastics in each product becomes important at world scale (104).

Finally, the presentation of the project was presented to the SQD team, for a possibility to implement these eco-design tools and processes in the long term. The results were that considering the economic aspect, the benefits brought by the tools in terms of eco-designed products developed are interesting and exploitable. The use of tools such as the TRIZ matrix will be difficult to systematize, but the results given in the case of the helmet will probably be exploited for future products developed. Indeed, environmental concern begins to be considered at Intersport, with initiatives such as the creation of the Green Series label or GOTS certifications. With the necessity to create products adapted to the demand of customers from whom concerns about recycled and eco-designed products is rising, the initiatives of Intersport toward eco-design will increase in the years to come.

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Appendix

<u>Appendix 1: List of the 39 parameters of the TRIZ matrix</u>

1. Weight of moving object	11. Stress or pressure
2. Weight of stationary object	12. Shape
3. Length of moving object	13. Stability of the object's composition
4. Length of stationary object	14. Strength
5. Area of moving object	15. Duration of action by a moving object
6. Area of stationary object	16. Duration of action by a stationary object
7. Volume of moving object	17. Temperature
8. Volume of stationary object	18. Illumination intensity
9. Speed	19. Use of energy by moving object
10. Force	20. Use of energy by stationary object
21. Power	31. Object-generated harmful factors
22. Loss of Energy	32. Ease of manufacture
23. Loss of substance	33. Ease of operation
24. Loss of Information	34. Ease of repair
25. Loss of Time	35. Adaptability or versatility
26. Quantity of substance/the matter	36. Device complexity
27. Reliability	37. Difficulty of detecting and measuring
28. Measurement accuracy	38. Extent of automation
29. Manufacturing precision	39. Productivity
30. External harm affects the object	

Appendix 2: Second presentation to the Intersport team


I-Définitions
ECO-CONCEPTION
Intégration de critère environnementaux dans le cycle de vie d'un produit
DIFFÉRENCES AVEC L'ÉCONOMIE CIRCULAIRE
Objectif de préservation des ressources pour les deux, mais différences dans la méthode de consommation
UN EXEMPLE D'INNOVATION ECO
Sèche-main DYSON


II-Méthodes de recherche
L'ÉCO-CONCEPTION POUR LES PRODUITS MATÉRIELS
Catégories étudiées, solutions trouvées...


Catégories
-Bagagerie
-Raquettes
-Balles
-Ballons
-Flottabilité
-Gourdes
-Bonnets de bain
-Tapis de yoga
Catégorie: Bagagerie
Produit: HEAD GRAVITY

Ma démarche

RECHERCHE DE TYPE "TRIALS & ERRORS"

Recherche désordonnée avec mes connaissances

UTILISATION D'OUTILS PRÉCIS

Utilisation d'outils de recherche systématique et répondant au besoin

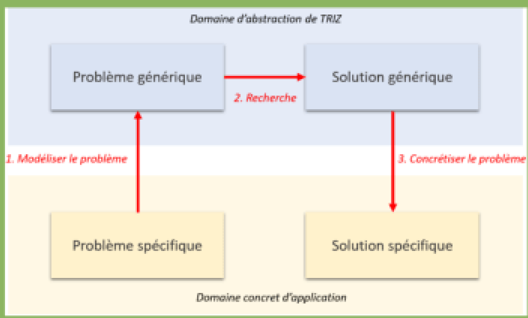
PRODUITS ÉCO-CONÇUS

Développement de produits optimisés d'un point de vue éco

La méthode TRIZ

THÉORIE DE RÉSOLUTION DES PROBLÈMES INVENTIFS

L'évolution d'un produit est prévisible et les problèmes dont il est sujet peuvent être anticipés



Principe de la démarche TRIZ

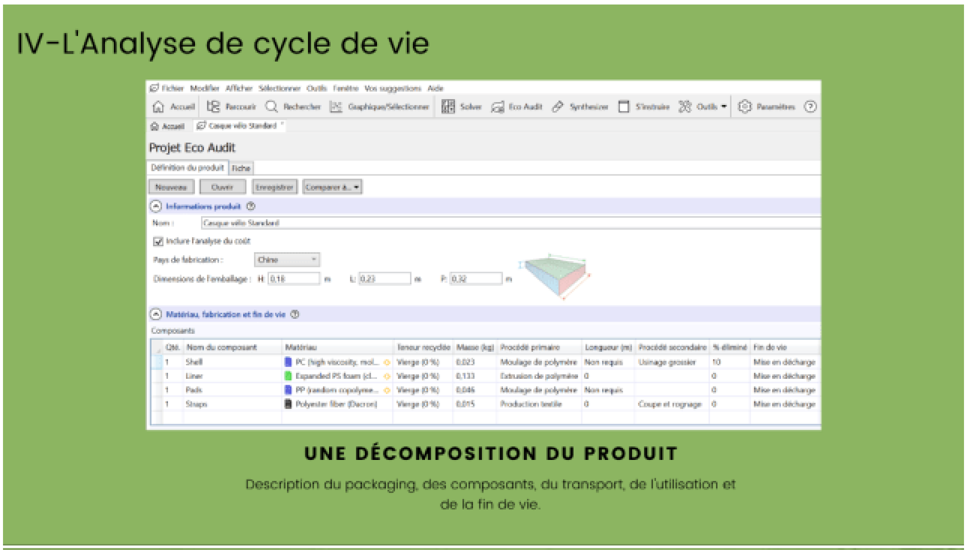
Matrice TRIZ

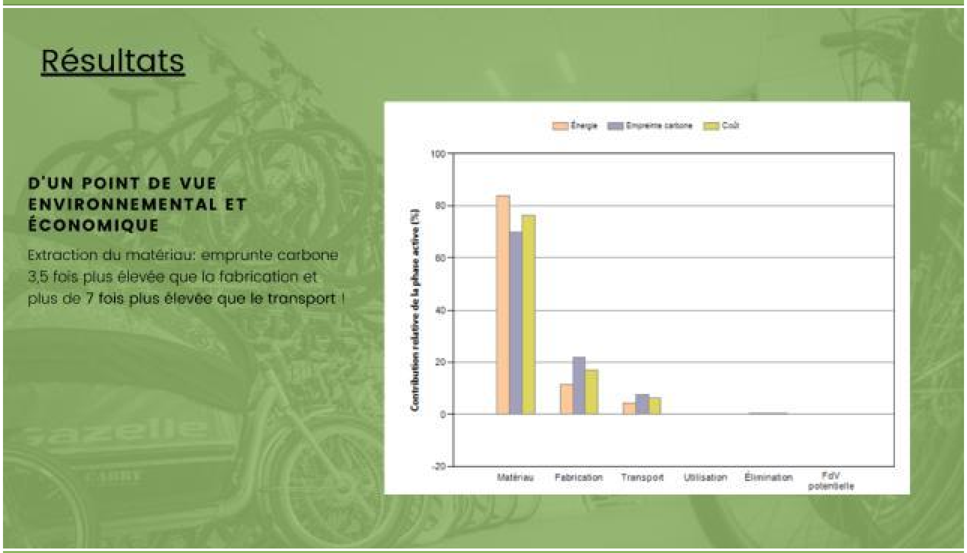
UTILISER UNE CONTRADICTION POUR TROUVER UNE SOLUTION

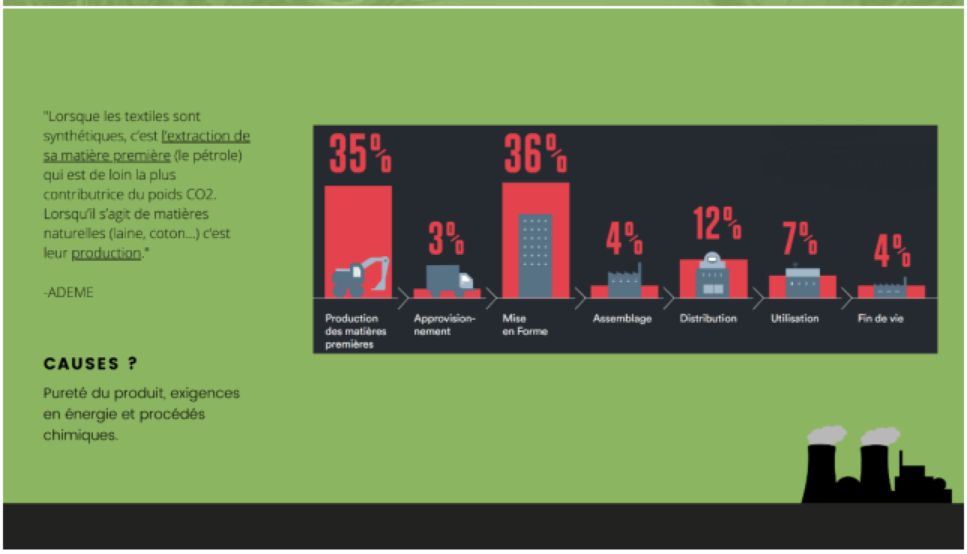
2 paramètres d'entrée: 1 effet positif à garder et 1 effet négatif à supprimer.


III-Exemple du casque de vélo
Problème spécifique:
Je veux diminuer la quantité de plastique utilisé MAIS je veux qu'il conserve sa capacité à protéger la tête.
Problème générique:
Je veux diminuer le volume, mais conserver la résistance du produit.
Solution générique:
Solution trouvée par la matrice TRIZ: Utiliser des matériaux composites.
Solution spécifique:
Utilisation d'un composite à base de liège et d'EPS dans le casque.


Exemple de casque éco-conçu
CASQUE 'ÉCO REACT'
Produit de la marque Bollé, avec un liner à 20% en liège.


IV-L'Analyse de cycle de vie
Projet Eco Audit
UNE DÉCOMPOSITION DU PRODUIT
Description du packaging, des composants, du transport, de l'utilisation et de la fin de vie.


Résultats
D'UN POINT DE VUE ENVIRONNEMENTAL ET ÉCONOMIQUE
Extraction du matériau: emprunte carbone 3,5 fois plus élevée que la fabrication et plus de 7 fois plus élevée que le transport !
Énergie
Empreinte carbone
Coût
Contribution relative de la phase active (%)
Matériau
Fabrication
Transport
Utilisation
Élimination
FdV potentielle


"Lorsque les textiles sont synthétiques, c'est l'extraction de sa matière première (le pétrole) qui est de loin la plus contributrice du poids CO2. Lorsqu'il s'agit de matières naturelles (laine, coton…) c'est leur production."
-ADEME
CAUSES ?
Pureté du produit, exigences en énergie et procédés chimiques.
35%
3%
36%
4%
12%
7%
4%
Production des matières premières
Approvision-nement
Mise en Forme
Assemblage
Distribution
Utilisation
Fin de vie


Résultats
COMPARATIF ENTRE DIFFÉRENTES OPTIONS
Etude pour un casque "classique" avec coque en PC, et d'un casque "éco-conçu" avec un liner en liège.
Énergie
CO2
Copier
Imprimer
Aide
Transport


RÉSULTATS
694 à 815kg de CO2
NON CONSOMMÉ SUR UN SEUL MODÈLE


IV-En quoi ces outils me sont utiles ?
MÉTHODE DE RECHERCHE
Structuration de la méthode de recherche de produits
CONTRÔLE DU PRODUIT
Connaissances accrues sur les matériaux utilisées, leurs prix...
SOLUTIONS INNOVANTES
Permet de développer la créativité dans la recherche de solutions à un problème
PRISE EN COMPTE DE L'ENVIRONNEMENT
Bénéfices environnementaux faciles à mettre en place.
Informations supplémentaires
ECO-CONCEPTION ET ÉCONOMIE CIRCULAIRE
https://www.eco-conception.fr/static/economie-circulaire.html
L'APPORT DE LA CRÉATIVITÉ DANS LE PROCESSUS D'ÉCO-CONCEPTION
https://tel.archives-ouvertes.fr/tel-00662434