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1. Problem Statement

About 92 million tons of textile waste are produced every year. Less than one-fourth of them get recycled, and the rest end up in landfills. These mountains of textile waste are costing us a lot of money and a lot of water (earth.org, 2022). To deal with this pressing problem, the European Commission is currently framing the Eco-design for Sustainable Products Regulation (ESPR) which will come into effect by 2026. Under this regulation, all companies selling textile products in the EU will be required to have the Digital Product Passport (DPP) for each of their products. The digital product passport will have information about the product's environmental qualities and characteristics, such as origin, composition, and recyclability. All this information will bring a revolution in transparency, which will not only enhance communication between producers and recyclers but also raise customer awareness and facilitate better decision-making. The digital product passport perfectly aligns with the EU's strategy for sustainable and circular textiles, which encourages producers to consider the environmental footprint throughout the entire life cycle of product *i.e. from design to end-of-life disposal (European Commission; GSI 1; Digital Europe)*.

Companies currently face significant challenges regarding the practical implementation of the DPP, particularly concerning recyclability. Recyclability refers to the ability of a product or material to be collected, processed, and transformed into new products or materials through recycling processes. Our challenge collaborator Westwing was facing this problem surrounding recyclability when they approached the EuroTeQ collider three months ago. Westwing is a Home and Living e-commerce company founded in 2011 and present in 11 European countries, including France. In February 2020, France passed the AGEC law, which mandates all producers to disclose certain information about the environmental qualities and characteristics of their products along with the packaging (Republique Francaise, 2022). The AGEC law, which stands for Anti-Waste for a Circular Economy, wants to encourage producers to rethink their design and production to eliminate waste and promote a circular economy. The AGEC law mandated the producers to disclose information on five components: the incorporation of recycled

materials, the release of microplastics, the presence of hazardous substances, traceability, and recyclability. While the Westwing company could display information on the first four components, it was challenging to approach recyclability. This, because the AGEC law did not specify any formula to calculate the recyclability of a product (trustcase; scantrust). Hence, it was difficult for Westwing to comply with the French AGEC law. As research was made, it became evident that the issue of calculating recyclability was not unique to Westwing, but rather a common challenge faced by numerous companies.

Presently, many companies are employing their own distinct formulas, which consider varying criteria to calculate recyclability. Therefore, the absence of a standardized calculation that incorporates a consistent set of criteria. Thus, when information for recyclability is needed to be considered in the Digital Product Passport, a lack of this calculation will lead to lack of comparability and diminished consumer trust. This is the reason, while dealing with this challenge, we developed a standardized method to calculate the recyclability index, which considers five distinct criteria. Furthermore, the recyclability index is then transferred to a color-coded recyclability rating scale, which displays the recyclability rating of a product in an easy format for consumers.

2. Methodology

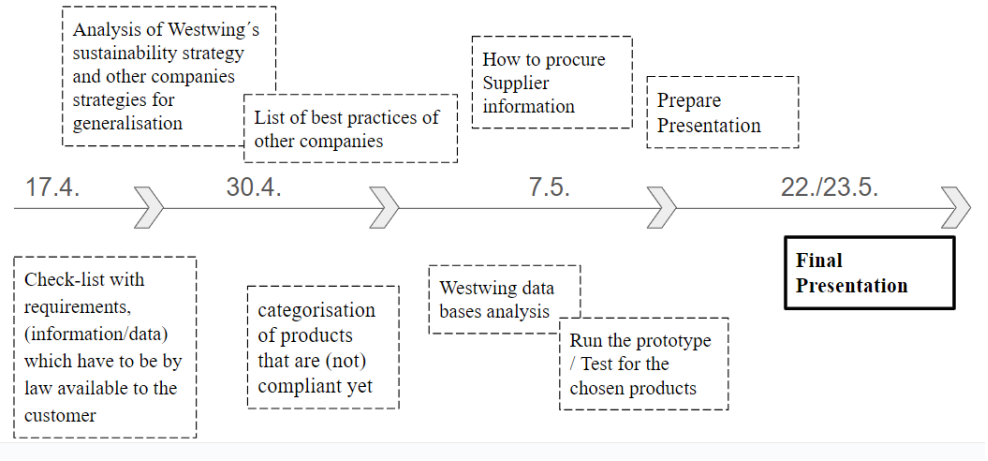
In collaboration with Westwing the first need was to answers three main questions for which the methodology was approached as followed (see table 1):

Table 1.: Main questions and methodology:

Question	Methodology
1. Which requirements are stated in the law that are important for Westwing's compliance?	Law Analysis: careful reading and analysis of the original law, together with questions and answers in collaboration with the legal team of Westwing.
2. Which products are already compliant with the law?	Gap Analysis: comparison of requirements vs current available data from the products.
3. How can the required information be collected from the suppliers and stakeholders in a cost and time-efficient way?	a) Supplier Guideline with the basic context and definitions needed. b) Excel Product Sheet as collector tool to build a database.

Based on these requirements a timeline was developed (see figure 1).

Figure 1.: Timeline



After the main questions and timeline were clear, the development of the standard method to calculate recyclability became the main target. To develop such a method to calculate the recyclability of a textile product for the European Union, the proposal was based on the AGEC directive, specifically the French Decree 2022-748 and combined them with our own research.

For the first source, the AGEC directive, it was considered the definition the article VI of this law gives to recyclability: “The recyclability of a product is assessed by the follow criteria:

1. The ability to be efficiently collected across the national territory, through the population’s access to nearby collecting points.
2. The ability to be sorted in recycling channels.
3. The absence of material limiting the sorted, recycling or usage of the recycling materials.
4. The ability to include 50% of recycled material in the final recycled product.
5. The ability to recycle the product on an industrial scale and economically viable.”

(Republique Francaise, 2022)

As a second step, research was conducted to determine the existence of standards for recyclability, encompassing both the textile and other industries, and discover which calculation methodologies were employed. A multitude of global instances of various industries, companies and governments were uncovered, all attempting to form some type of standards- with no or limited success. Also discovered a trove of research discussing the feasibility of implementing such standards, and the possible methodologies needed to create them. Afterwards a few that highlighted our focal points were selected and they drew inspiration from a new, innovative solution.

The Nordics are one of the leading regions for textile circularity, and while they have no official industry-wide standards, as of now there is a plethora of research on the matter. One paper (Dukovska-Popovska et al.,2023) goes into detail about a potential calculation method which takes the Nordics as a region, breaking it down by country level and then taking three factors: the volume of textiles produced, the composition of the textiles and finally the country's annual capacity for sorting and recycling textiles. This concept of establishing the composition of the product (in this case, textiles), as well as factoring in the facilities in a country, proved an inspiration to a own solution later in the process.

Another, older study focused primarily on the construction industry with the goal of establishing a recyclability index for materials used in buildings (Vefago, 2013). Since no such standardized index existed, this paper set out to create a methodology to reliably calculate and index materials commonly used in construction, assigning them labels of either "reused", "recycled", "infraused" and "infracycled", but also "non-renewable virgin materials" for those materials with no recyclability. While this paper did lay out some interesting concepts in the idea of creating a reference database for materials (an idea we later drew inspiration from), it did not go deep enough to cover all the aspects such index needs.

Finally, (Hiroshige et al, 2002) developed the need to create a solution similar to the one envisioned- the creation of a recyclability calculation, in this case aptly named the "Recyclability Evaluation Method" or REM While it mainly focused on consumer

electronics, and the end result was quite rudimentary- as it was limited by the knowledge of the times- it set a good framework for why such a method was not just useful, but indeed critical, to any manufacturing in the future. It took not only the environmental consideration of the manufacturing but put a heavy emphasis on the impact of disassembly and recyclability of parts thereafter. The paper discusses incorporating circularity into the product lifecycle, citing existing and upcoming regulations in both Japan and globally that would necessitate such methods going forward. This paper helped gain scope in how such regulations have been evolving in the past 20 years and will only become stricter and require more efficient and more detailed methods across every industry.

After a clear way to develop a standard index was developed, policy research was made as a third and final step. The research question for this final pace was how can a standardized index for recyclability be implemented on the European level? The solution found was the European Product Passport, which will mandate all textile producers inside the EU to disclose environmental characteristics of their products to promote circularity and improve transparency for customers and boost sustainability along the entire value chain. But since there is no single standard for recyclability it is lacking comparability. This is the political space where a comprehensive recyclability index through a holistic approach to ensure product comparability for the consumer is fitted.

3. Final Concept - Recyclability Index for the Textile Industry

The proposed recyclability index is a standardized methodology that holds significant potential for application across various textile products, offering a valuable decision-making tool for both political and enterprise entities. By establishing a comprehensive framework, this index serves as a bridge, connecting diverse stakeholders and government entities. The methodology employs a multi-criteria approach, encompassing essential factors to accurately assess recyclability. Through the calculation of these criteria, the resulting index gives end users a uniform foundation upon how to compare the sustainability and recyclability attributes of different products. The adoption of such a scientific approach holds promise for advancing the field of textile recycling and promoting informed decisions among stakeholders.

The recyclability index consists of five components:

1. Waste collection access.
2. Industrial recycling scale.
3. Recycling energy consumption.
4. Product's recycled content.
5. Non-limiting recyclable materials.

Each of these components have an equal weight of 20% in the final index, therefore they reflect a balanced importance for each.

3.1 Waste collection process

The primary objective of this component is to ensure an adequate number of recycling centers to effectively recycle materials. This component can be implemented at various levels, ranging from local to national, depending on the scope of application. It takes into consideration the ratio of recycling facilities or industries available for material recycling

per the number of inhabitants in each region. These facilities should possess appropriate technology and regulatory approvals to qualify under this category.

The access score can be calculated using the following formula:

Access = (Number of recycling centers / Millions of of inhabitants)

Figure 2.: Number of recycling centers in France (Source: gouvernement.fr (2022))

As an example, let's consider the case of France. According to data from gouvernement.fr in 2022, France had a total of 4591 recycling centers and a population of approximately 68 million people. Using the mentioned formula, we obtain a value of 67.51 recycling centers per million people.

To establish a definitive score for this criterion, it is needed to define a threshold value in consultation with the European Union, other governmental entities, and relevant experts and stakeholders. This collaborative process will ensure that the final score reflects the consensus and input of all concerned parties.

3.2 Industrial recycling scale

To ensure the presence of technologies or methodologies capable of recycling individual components of a product within a specific region. It is crucial to assess the availability of industries or companies capable of handling and recycling those materials. This component, referred to as the "Industry" factor, is calculated as the ratio of,

Industry = (number of recyclable materials / total number of materials)

Figure 3.:Product from Westwing.

For example, let's consider a pouf as a product from Westwing (see Figure 3). This pouf chair comprises four different materials: wood, foam, plastic, and fabric. If there are established companies in the region capable of recycling all these materials, the "Industry" component would receive the full 20% score in the final value. However, if a company is not available to recycle any one of these materials, the 20% score would be multiplied by the corresponding ratio to determine the result.

It is important to note that specific data and sources need to be provided to accurately assess the availability of recycling industries for each material within a given region.

3.3 Recycling energy consumption

This criterion evaluates the amount of energy required to efficiently recycle various materials. Energy consumption is a crucial indicator for assessing the sustainability and emission performance of recycling technologies (Krajnc, D. et al., 2003). Different materials require distinct technologies and machinery for recycling, resulting in varying energy requirements.

To determine this criterion, the energy needed to recycle each material per kilogram (KG) is calculated and subsequently aggregated to obtain the final energy value. A threshold scale must be established after consultation with the European Union and relevant

experts and stakeholders. This threshold scale will be used to determine the final score for this criterion.

As an example, consider a pouf composed of four different materials: wood, fabric, foam, and plastic. Recycling each material requires different methodologies. Typically, wood requires 60 kWh per Kg, fabric requires 10 kWh/Kg, foam needs 0.1 kWh/Kg, and plastic demands 50 kWh per KG to be recycled (Massoud, M. et al., 2023). Consequently, the calculated value for energy consumption, obtained by multiplying the quantity of each material by its respective energy requirement, amounts to 604 kWh per KG. Depending on the established threshold scale, this calculated value will contribute to the final score for the energy consumption criterion.

It is important to note that the specific energy consumption values mentioned in this example are fictional and are provided solely for illustrative purposes. Therefore, a proper accurate database is needed to define real values.

3.4 Product's recycled content

The incorporation of recycled materials in the production of new materials is a pivotal step towards achieving sustainability and promoting recycling practices. In assessing the recyclability of a product, it is crucial to evaluate the extent to which recycled materials are used during its manufacturing process. This criterion plays a significant role in determining the overall environmental impact of the product.

Generally, a product comes from the combination of various materials with different weights. In the specific case of a pouf, the following proportion of recycled content is presence: Wood - 10% * 10 Kg, Fabric - 0% * 0.2 Kg, Foam - 0% * 0.15 Kg, and Plastic - 0% * 0.05 Kg. Considering these percentages, it can be concluded that 10% of the materials used in the pouf are derived from recycled sources.

The percentage of recycled material content influences the scoring of this criterion. In this instance, where the pouf consists of 10% recycled content, the criterion's final value would be 2% (considering it represents 20% in the final index). The higher the proportion of recycled materials used, the greater the score would be, thus indicating a higher level of sustainability and adherence to recycling principles.

In scientific and industry assessments of recyclability, the incorporation of recycled materials is recognized as an important factor in promoting a circular economy and reducing waste generation (UNEP). Moreover, it can contribute to the reduction of greenhouse gas emissions and support the transition towards a more sustainable and circular approach to material usage (Reck et al., 2012).

3.5. Non-limiting recyclable materials

The final component of the recyclability index focuses on the incorporation of composite materials in the manufacturing process. In this context, composite materials refer to materials that pose challenges for recycling due to factors such as being non-recyclable, requiring significant energy and investment for recycling, and lacking available technologies for effective recycling. Consideration of this component aims to ensure the utilization of appropriate and environmentally friendly raw materials in the production of goods.

Considering the Pouf example, no raw materials are present that limits the recycling process. Therefore, this component receives a full score of 20%.

It is important to prioritize the use of recyclable materials in product manufacturing as it promotes a circular economy and reduces environmental impact. By incorporating recyclable materials, the overall sustainability of the product is enhanced, leading to resource conservation and waste reduction. This aligns with the principles of sustainable development and responsible production.

In conclusion, the recyclability index provides valuable information for customers to make sustainable choices when purchasing textile products. By considering the different components of the index, such as access to waste collection, industrial recycling scale, energy consumption of the recycling process, incorporation of recycled materials, and absence of materials limiting recycling, customers can assess the environmental friendliness and potential for future recycling of a product.

By utilizing the recyclability index, customers can make informed decisions that align with their sustainability goals. They can choose products with higher scores on the index, indicating better recyclability and reduced environmental impact. This empowers customers to contribute to the circular economy, promote resource conservation, and reduce waste generation.

The adoption of the recyclability index in the textile industry can also encourage manufacturers to prioritize recyclable materials and implement sustainable production practices. Ultimately, the widespread use of the index can drive positive change towards a more sustainable and environmentally conscious textile industry.

By making conscious choices based on the recyclability index, customers can play an active role in promoting sustainability and supporting the transition towards a more circular and eco-friendly economy.

4. Future Outlook

By focusing on creating a simplified and standardized recyclability rating index, customers, governments and companies stand to benefit. This uniformity will enable governments to set up better mechanisms to monitor compliance, companies avoid paying consulting firms to design complicated indexes and customers have a reliable standard that can aid them in making more sustainable purchase choices.

Having already had preliminary discussions with a member of the European Parliament (team of Anna Cavazzini) and receiving positive feedback, the project is well poised to integrate within the EU Digital Product Passport (DPP) and the CIRPASS team. By integrating and collaborating at an early stage with CIRPASS, The EU Commission & The EU Product Passport results in numerous potential synergies. Potential bottlenecks can be identified during the development phase itself. For the pilot phase, France serves as a viable local market since the French government already has a head start with the implementation of the AGEC Law. Given that French companies are already mandated to disclose recyclability information of products sold to consumers (SgT, 2023), there is already a need for our index.

Using the learnings from the pilot phase and once the EU Digital Product Passport is ready in 2026 (The EU Digital Product Passport: How Can Companies Prepare for It Today? , n.d.), a gradual European wide expansion is on the cards.

The long-term goal of our project is for the index to be one of the contributing factors to a truly circular economy within the EU. Once the index is well integrated with the Digital Product Passport, governments can also consider setting a minimum standard criterion. An example for a mandatory standard can be that products must score at least 20% on the recyclability rating index for it to be sold in the European Union.

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6. Appendix

Westwing SKU	Supplier SKU	Material Type	Total Weight (in grams)	Recycled Material (weight in grams)	Type of Hazardous Substance	Name of the Hazardous Substance	Hazardous Substance (weight in grams)	Synthetic Microfibre (weight in grams)

(Supplier Product Data Sheet)

Westwing SKU	Supplier SKU	Total Weight (in grams)	Type of Textile Material	Recycled Material (weight in grams)	Type of Hazardous Substance	Name of the Hazardous Substance	Hazardous Substance (weight in grams)	Synthetic Microfibre (weight in grams)	Dying (Country of Origin)	Weaving(Country of Origin)	Printing(Country of Origin)	Confection (Country of Origin)

(Supplier Textile Product Data Sheet)

	A	B	C	D	E	F	G
1	Westwing SKU = Column A	Supplier SKU = Column B	Type of Packaging Material =Column C	Total Weight (in grams)	Recycled Material (weight in grams)	Reused Packaging	Reusable Packaging
2							
3							
4							
5							
6							
7							
8							
9							

(Supplier Packaging Data Sheet)

Product Description +

Shipping & Return +

About the brand +

Customers' opinion ★★★★★ (5) +

Product Sheet on Environmental Qualities and Characteristics -

Incorporation of Recycled Materials	Product contains at least 10% recycled materials Packaging contains at least 70% recycled materials
Recyclability	20% Recyclable Product Fully Recyclable Packaging
Presence of Hazardous Substances	None
Microplastics	Product does not release Microplastics
Traceability	Dying, Weaving, Printing and Confection was done in China

(Product Sheet on Environmental Qualities and Characteristics)

(Visualization of the rating index on an e-commerce website)