Circularity Index:

Methodology

Index

Introduction

The present methodological report presents the indicator developed by CESQA of the University of Padua that aims to measure how circular are the garments commercialized by OVS S.p.A. The Circularity Potential Index for Textiles considers the garment's life cycle stages that have the most relevant impact on the circularity of garments that are raw material origin and production and the end-of-life stage. In particular, it considers the state of the art of recycling and recovery of textiles. It can take a value between 0 and 10, whereby 0 corresponds to a completely linear product and 10 to a completely circular product.

The present report presents the calculation method and the hypothesis applied, the goal and scope definition with the boundaries of the system considered. To increase comprehension some examples are reported. Finally, some future development will be suggested.

To develop the new index, some preliminary studies regarding circularity measures and recycling processes for textile waste were made.

Some circularity measures were considered from literature and evaluated it terms of construction validity, reliability, transparency, and generality. Results show that the circularity measure with the higher score is the Circularity Footprint Formula (Zampori L., 2019) proposed by the European Commission in other to model the end-of-life in the Product Environmental Footprint.

In parallel to this study, recycling processes for textiles waste were tabulated in relation to feedstock requirements. Tabulation and other details are reported in this document in Appendix A.

The present report presents the calculation method and the hypothesis applied, the goal and scope definition with the boundaries of the system considered. To increase comprehension some examples are reported. Finally, some future development will be suggested.

1. Goal and Scope Definition

The goal for this study is to develop a new life cycle base circularity index for textiles and apply it to OVS S.p.A. (OVS) products. This index will replace the previous one present in ECO VALORE, so it will be reported together with water consumption and CO_2 emission for each garment. The index score must be easy to convey since il will be communicated to the consumers according to transparency goal of OVS.

Aim of this index is to improve the previous version providing at the same time useful information for product design considering product end of life management. Moreover, it must be applicable to a high number of textile garments within their high variability on composition.

1.1. Declared unit

The declared unit is expressed as: “one garment item of OVS S.p.A.”. The result of the evaluation is expressed per garment and refer to 1 kg of the product considering composition proportional to the actual one.
As example, if an OVS textile product weights 0.4 kg and is made by 50% cotton and 50% polyester the declared unit will consider 0.5kg of cotton and 0.5kg of polyester.
Considering the same weight for all items allows comparison in terms of material used allowing to make useful product design considerations.

1.2. System Boundaries

To evaluate potential circularity of each individual garment, the following stages of the life cycle have been considered: extraction and production of raw materials, yarn production and the end of life (i.e., closed-loop recycling, open-loop recycling, energy recovery or disposal).
This excludes stages related to processing (i.e., fabric formation, cutting, finishing), transport and distribution, sales, purchasing transactions and consumer use and reuse. Even if some of those stages have a significant impact, they were not considered as the aim of this study is to focus on other details such as origin of materials, their composition, and their end-of-life destination.

***Table 1**: Stages considered, highlighted in blue, and neglected, highlighted in grey.*

Stages considered are highlighted in blue in table §1, so results will be represented from cradle to gate and from gate to grave. The first gate was placed after yarn production because before it there is a high differentiation of processing in relation to materials; for the same reason the second gate was placed after use phase.

Reuse phase, that is usually included in the recycle phase, is here included in the use one, as this model wants to give a better understanding of what happens after it, in relation to the characteristics of the garments.

After an overview of all main textile materials and recycling processes for textile waste available nowadays, the following parameters were taken under consideration for each garment:

- Composition, expressed as the overall material composition.
- Origin of the material, more specifically if the textile item is made by a secondary raw material, traditional primary raw material of if it comes from innovative primary raw material, (i.e., biological, biomass, innovative processes with certification).
- Colour, considering if the garment is multicolour or monocolour. In relation to this parameter some recycling process will be available or not.
- Number of components, both number of main components, (i.e., main fabric, lining and padding,) and number of overall components. This to understand the magnitude of preparation process before recycling.

Considered stages were evaluated considering greenhouse gasses emissions for each single processes, as defined in the next paragraphs.

1.3. Assumptions

To perform the study the following initial assumption about garments details, economic considerations, choice of end-of-life destination and allocation were made:

1. Zip, buttons, labels, and stamps were not considered, as their presence is not reported in OVS database. Their presence should be considered as they require a more demanding preparation before recycling, and as they represent a waste. Nowadays, according to MUD Jeans and Recuprenda, there are machines available to recognise and take them off from garments, but

as they are made from too many different materials buttons and especially zips are not fit for recycling jet. MUD Jeans is starting to face the problem related to buttons, making them using only stainless steel.

2. Economic considerations were not made, but to return reasonable results only recycled processes available in the market has been considered. There are many processes in phase of study or that need to scale up that were not considered.

3. A textile product is assumed to go, at its end-of-life, to its best option in terms circularity, i.e., impact avoided.

4. Authors (Sandin G. et al., 2018) often assume that products made from recycled materials replace products made from virgin fibres, so often is avoided allocation by system expansion. In this study allocation referred to closed-loop recycling was avoided by system expansion, while allocation for open-loop recycling was made considering Circular Footprint Formula's general guidelines.

5. Assumption about the replaced production of new products influence results considerably, thus the choice of replacement rate is crucial. For this study a substitution 1 to 1 is assumed, as it is not declared the percentage of recycled material, in addition to it there are no general rules, and lots of companies are increasing the percentage of recycled material in textiles products. The content of recycled also depends strongly on the recycled material origin and type of garments, as example jeans can be made 100% from recycled cotton, but T-Shit cannot usually, as they cannot ensure a good mechanical resistance. As, in general cotton fibres with a high length is used for underwear, medium length for T-shit, medium or smaller length for jeans.

2. Circularity Potential Index for Textiles

The Circularity Potential Index for Textile (CPIT) was built considering three different formulas deriving from modification of a formula proposed by the European Union, the Circular Footprint Formula (Zampori L., 2019):

- Linear Footprint Formula (LFF), that express the impact of a textile, in kgs of CO_2 equivalent, at its linearity. Considering traditional raw materials that goes to disposal at their end of life.

- Potential Circular Footprint Formula (PCFF), that express the impact of a textile, in kgs of CO_2 equivalent, at its maximum circularity. Referring to secondary raw material or innovative primary raw material that goes at its best option at end-of-life.
- Modified Circular Footprint Formula (MCFF), that express the impact of a textile, in kgs of CO_2 equivalent, at its actual state. Considering the garment raw material that goes at its best option, in terms of impacts avoided, at its end-of-life.

The formula for the new circular index is the following:

$$CPIT = \left(0 - 10\frac{MCFF - PCFF^*}{LFF^* - PCFF^*}\right) * P$$

Where $\mathrm{PCFF}^* = \min\left(\mathrm{PCFF}_S\right)$ and

$\mathrm{LFF}^* = \max\left(\mathrm{LFF}_S\right)$,

represents the two extremes value corresponding to a CPIT value of 10 and 0 respectively. Calculation needed to perform MCFF, LFF and PCFF will be performed in paragraphs §2.2., §2.3., and §2.4., and refers to the overall composition of item's main components (i.e., main fabric, lining and padding). Parameters P considers penalties and will be discuss in section §2.5.

2.1. Circular Footprint Formula (CFF)

This formula was proposed by the European Commission in other to model product end-of-life Product Environmental Footprint (Zampori L., 2019) proposed by the "Single market for Green Product" EU program.

The Circular Footprint Formula is made up by summation of three components:

1. Material.

   This element accounts for life cycle inventory related to primary material, secondary material input and material recycling process minus the credit for avoided primary material, and is defined whit the following formula:

   $$(1-R_1)E_v + R_1\left(AE_{recycled} + (1-A)E_v\frac{Q_{Sin}}{Q_p}\right) + R_2(1-A)\left(E_{recyclingEoL} - E_v^*\frac{Q_{Sout}}{Q_p}\right),$$

   Where parameters E_v, $E_{recycled}$, $E_{recyclingEoL}$and E_v^* are respectively specific emissions and resources consumed arising from acquisition and pre-processing of virgin material, the recycling process of the recycled(reused) material, the end-of-life recycling process and from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials. While R_1 and R_2 represent the proportion of material in product input that comes from recycling and the proportion of material in the product that will be recycled. Allocation factor A, of burdens and credits between supplier and user of recycled materials, is determine from the analysis of the market situation: 0.2 if low offer and high demand, 0.8 if high offer and low demand, 0.5 equilibrium between offer and demand. Finally, Q_p, Q_{Sin} and Q_{Sout} parameters are respectively quality of the virgin material, quality of the recycled material at the point of substitution and quality of the recyclable material at the point of substitution.

2. Energy.

   Accounting for life cycle inventory related to energy recovery process minus the credit for avoided primary energy, is described as:

$$(1-B)R_3(E_{ER} - LHV X_{ER,heat} X_{SE,heat} E_{SE,heat} - LHV X_{SE,elec} E_{SE,elec})$$

   Where parameters E_{ER}, $E_{SE,heat}$ and $E_{SE,elec}$ are specific emission and resources consumed arising from energy recovery process, that would have arisen from the specific substituted energy source, heat and electricity respectively. R_3 is the proportion of material in the product that is used for energy recovery at end-of-life. B is the allocation factor of energy recovery process; in PEF studies it shall be equal to 0. LHV is the lower heating value of the material in the product that is used for energy recovery. Finally, $X_{ER,heat}$and $X_{SE,elec}$is the efficiency of the energy recovery process for both heat and electricity.

3. Disposal.

   This third component accounts for the life cycle inventory of the disposal of remaining waste, and is characterized as:

$$(1-R_2-R_3)E_D$$

   Where E_D is the specific emission and resources consumed arising from disposal of waste material at the end of the analysed product, without energy recovery.

2.2. Modified Circular Footprint Formula (MCFF)

Starting from the formula described in paragraph §4.1 the Modified Circular Footprint Formula was built by:

- Considering parameters E referring to emission related to greenhouse gasses only.
- Dividing primary raw material into traditional primary raw material, with an associated impact E_v and innovative primary raw material with as associated impact of E_o. As innovative primary raw material it will be consider mainly material from renewable, biological resources

that have the aim to avoid consumption of finite resources (fossil and soil) and raw material coming from innovative processes with certification. According R_o will represent the proportion of material in product input that comes from innovative primary raw material.

- Considering recycled material and material that goes to a close loop recycle characterized by 100% recycled content, so allocation is avoided.
- Considering allocation, A, for open-loop recycling equal to 0.8 as suggested in the Product Environmental Footprint initiative for recyclable material with a high offer and low demand. While for closed-loop recycling allocation is not considered so A=0.
- Disposal was not considered as an option for end-of-life, as better options exists.

$$MCFF = (1 - R_0 - R_1)E_v + R_0E_o + R_1E_{recycled} + R_2(1 - A)\left(E_{recyclingEoL} - E_v^* \frac{Q_{Sout}}{Q_p}\right) + R_3E_v(E_{ER} - LHVX_{ER,heat}X_{SE,heat}E_{SE,heat} - LHVX_{SE,elec}E_{SE,elec})$$

2.3. Linear Footprint Formula (LFF)

Linear Footprint formula was built considering as if all material was made with traditional primary raw material, with an associated impact E_V, and goes to disposal in its end-of-life, with an associated impact E_D, resulting in the following formula:

$$LFF = E_V + E_D$$

2.4. Potential Circular Footprint Formula (PCFF)

Potential Circular Footprint Formula is the following, it slightly differs from MCFF as the only difference is that no material is considered from traditional primary raw material.

$$PCFF = (1 - R_1)E_O + R_1E_{recycled} + R_2(1 - A)\left(E_{recyclingEoL} - E_v^* \frac{Q_{Sout}}{Q_p}\right) + R_3E_v(E_{ER} - LHVX_{ER,heat}X_{SE,heat}E_{SE,heat} - LHVX_{SE,elec}E_{SE,elec})$$

2.5. Penalties (P)

Addition of penalties is made considering that more complex a garment is, the higher will be operation required to its recyclability, so the higher will be the probability of non-close-loop recyclability and the impact related.

Complexity is here related to the number of components, here also non primary components such as lace, hood lining, etc are considered, while presence of zips, buttons and labels will not be encountered. Estimation of the number of components related to an item will be made considering its commodity function, since the number of components present in OVS database, is subjected from strong personalization of the product manager.

After calculating $PCFF^{*}$ and LFF^{*} a penalty with respect to complexity of the garment will be calculated. The penalty factor P limits will be fixed considering that the maximum penalty related to complexity will correspond to open-loop recycling or energy recovery. From this step the *Circularity Potential Index for Textile* (CPIT) will be obtained.

This contribution won't be added to garments that already go to downcycle or energy recovery and to garments made from cellulose-polyester bland, as they go to a chemical recycle solvent based that accept trim, so garments doesn't need separation of components.

3. Data inventory

	Life Cycle Phase		Primary Data	Source	
Cradle to Gate*	Raw Materials	Components	Main Fabric, lining, padding	OVS database	
		Components Weight	All components of a garments have the same weight		
		Materials	Acrylic, alpaca, cashmere, cotton (traditional, organic, better, recycled), elastane (standard, biobased), flax, glass fibre, hemp, jute, lyocell (standard, Tencel), metal fibre, modal (standard, Tencel), mohair, others, polyamide (standard, biobased, recycled mechanically, recycled chemically), polyester (standard, recycled chemically, recycled mechanically, Reprive), polyurethane, silk, viscose (standard, Ecovero), wool (traditional, recycled), textile paper.	From Higg.org, SimaPro (IPCC, 2013) and Literature	

	Yarn Formation	Operations	Extrusion, spinning, weaving	From Higg.org, SimaPro and Literature	
Gate to Grave**	End of Life	Closed-loop recycle, open-loop recycle, energy recovery, disposal		From Higg.org, SimaPro and Literature	

* First gate is placed right after yarn production.

** Second gate is placed right after use/reuse phase.

4. Application Examples

Composition:
62% ACRYLIC, 19% POLYESTER,
12% POLYAMIDE, 7% WOOL

Destination:
OPEN-LOOP RECYCLING

LFF	PCFF	MCFF	CPIT
11.74	6.27	10.50	2

Composition:
100% POLYESTER (RECYCLED)

Destination:
CLOSED-LOOP RECYCLING

LFF	PCFF	MCFF	CPIT
6.35	1.82	1.82	10

5. Future Development

Improvement of OVS database:

- Including the weight of main components (i.e., main fabric, lining, padding) expressed in g/m^2.
- Aligning the definition of garments components to a more objective one.

Improvement of greenhouse gasses (GHG) characterization factor database, fixing a biannual data improvement with the aim of generating a global value of CO_2 equivalent emissions for each material considered referring to stages and boundaries considered.

Improvement of the Circular Potential Index for Textiles, including consideration about durability in a design perspective. According to literature (Annis, 2012), durability is defined as the length of time that a garment has the ability to maintain and ensure its distinctive characteristics of **strength**, **dimension** and **appearance**. As it strongly depends on the thickness of the fabric, this improvement can be done once the weight of main components in g/m^2 is available. Durability will vary the index according to modification on the average lifetime (i.e., 52 washes) of a garment, so modifying the declared unit to a functional unit that takes into account the product use, referred to an average lifetime.

Appendix A

To map recyclable textiles waste interviews and websites of Radici Group, Filatura Astro, Officina +39, Lenzing, MUDJeans, Reverse Resources, Recuprenda and website of Purfi, Worn Again Technologies, Circ, Block Texx, Ambercycle, Gr3n, Teuin, Reprove, Carbios, Aquafil, Evrnu, Usna Yarns, Birla Cellulose, Infinitefiber, Renewcell, Cyclo Recycled were considered. Moreover, some reports (Hemkhaus, Hannak, Malodobry, & Janßen, 2019) and (Accelerating Circularity, 2021) were taken into account.

Textile composition	Accepted contaminations	Associated Recycle
100% Polyester	Multicolour, PET coatings	Chemical - depolymerization
100% Polyamide	Multicolour	Chemical - depolymerization
100% Cotton	<=2% of elastane, Ramie and Flax	Mechanical - fraying
100% Wool		
100% Cellulose	Multicolour, <=2% of elastane	Chemical - solvent based
Blend Cellulose-Polyester	Multicolour, Plastic trim, PET coatings	Chemical - solvent based
Blend Cellulose-rich	Multicolour, <=2% of elastane, plastic trim	Chemical - solvent based
Blend Polyester-rich	Multicolour, <=2% of elastane, plastic trim, PET coatings	Chemical - solvent based
100% Polyester	<=2% of elastane	Mechanical - extrusion
Mix with high concentration of Acrylic or polyamide > 10%	Mix with high concentration of Acrylic or polyamide > 10%, presence of >2% of elastane, presence of stamps and coatings, silk	Open-loop recycling
Presence of >2% of elastane		

Presence of stamps and coatings		
Presence of metallic fibre - glass fibre		Energy recovery

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