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Article

Weighting of circularity dimensions

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Abstract: Methods to determine the environmental consequences of circular strategies may be a prerequisite for the circular economy. However, the weighting factors of the criteria groups in the international L.1023 circularity scoring standard need to be determined beforehand. No comprehensive analysis of the connection between carbon footprint based life cycle assessment (LCA) results – of the product to be evaluated and redesigned – and these weighting factors has been published. Here a method, based on lifetime reduction and Analytical Hierarchy Process (AHP), for establishing weighting factors in the L.1023 standard for circularity scoring of electronic goods (EEE), is presented. The scope of the present investigation is the life cycle of a generic EEE evaluated with the L.1023 standard, AHP and carbon emissions. Statistical hypothesis testing at the single circularity score level shows that for the EEE example, the chance of mistakenly favoring the redesigned alternative over the status quo when they are in reality indistinguishable can be as low as 0.6%.

Keywords: Analytical hierarchy process; Carbon footprint; Circularity; Electronics; Life cycle assessment; Single score; Weighting.

1. Introduction

Circular Economy (CE) is thought to be the definitive solution to achieve sustainability if it can be accomplished with non-toxic and natural materials. Qualitative and quantitative methods to assess the circularity of products are rife [1–9]. However, none of them has yet been agreed as international standard for circularity scoring. Meanwhile, Life Cycle Assessment (LCA) is a tool for product sustainability evaluation [10,11] in which carbon dioxide emissions are most in focus.

Pena *et al.*, clarified the potentials of LCA and the need of its coherent application in the development, adoption, and implementation of CE worldwide to advance more effectively and efficiently towards environmental sustainability [12]. Ford and Fisher used primary energy analysis of the life cycle to confirm the environmental feasibility of using 100% recycled Acrylonitrile Butadiene Styrene (rABS) in the caseworks of small consumer electronic products (EEE) as a step towards more circular design and manufacturing [13]. Schulte *et al.*, analyzed the environmental consequences of electrophysiology catheters considering two modeling perspectives, the implementation of LCA, including a cut-off approach and combining LCA and a circularity indicator measuring multiple life cycles [14]. Collection rate was found to be an important parameter for successful overall circularity [14]. The influence of collection rate was also identified for mobile phones [15]. However, the focus was on larger product systems on not on the design improvement of one product. In any case, the present research focuses more on the immediate circular eco-design and its effect on the lifetime and the carbon score. Anyway, the L.1023 standard [1] from International Telecommunication Union's branch for Standardization (ITU-T) is a qualitative scoring method by which ICT goods and other EEE can be assessed from 0% (worst) to 100% (best) for circularity in three dimensions Product Durability (PD), Ability to Recycle, Reuse, Refurbish and Upgrade, equipment level (3RUe) and Ability to Recycle, Reuse, Refurbish and Upgrade, manufacturer level (3RUm). The ability to provide business models supporting CE is included in L.1023. However, LCA is merely addressed by availability and quality of the LCA study, and not by absolute carbon and LCA values. The present research will show how L.1023 and carbon scores can be combined for low carbon circular product design.

The assessment method outlined in L.1023 consists of three steps:

1. Setting the relevance and applicability (R) of each criterion for circular product design for the ICT good at hand.

2. Assess the margin of improvement (MI) of each criterion.
3. Calculate the circularity score from 0 to 100% for the ICT good at hand for all three criteria groups (CGs) PD, 3RUm and 3RUe.

This includes:

- Using a predefined value matrix (or formula) to identify the % score from 0 to 100 for each combination of $R \times MI$.
- Derive individual averages for the included criteria separately for all three CGs: PD, 3RUm and 3RUe.

However, for L.1023, no method for establish weighting factors for PD, 3RUe, 3RUm has been defined. As a result, single product circularity scores cannot be obtained with L.1023. Here an approach based on Analytical Hierarchy Process (AHP) is presented. The links to Life Cycle Assessment (LCA) results of a baseline and 75 redesigned generic electronic product (EEE) is also outlined.

AHP is very well known [16–18] as a method to derive weighting factors for multiple criteria and illustrate uncertainty trade-offs, and so is product life cycle carbon footprint (PCF) for determining relations between life cycle stages [19]. Bringing further clarity to the connections between Circularity Scoring (CS) and PCF scores for EEE is one of the goals of the present research.

For the first time the effect of product lifetime reduction is used with AHP to determine weighting factors for criteria groups within the L.1023 standard.

The scope of the present investigation is the production of one generic EEE with a lifetime of 5 years. The present research can support the application of the L.1023 circularity scoring by providing a method by which a single (%) score can be obtained instead of three different. The news value of the present research concerns the weighting factors for groups in a specific circularity scoring context and the role of PCF and related PCF scores.

2. Problem formulation

The present research focuses on finding a methodology for quantifying weighting factors for the scores for PD, 3RUe, 3RUm criteria groups of L.1023. In the present research the hypotheses are:

- AHP and product lifetime can be used to determine weighting factors for the three criteria groups of L.1023.
- The change in PCF score due to a change in weighted L.1023 score can be derived.

3. Research approach

The first step of the present research approach is to use the L.1023 standard [1] to calculate unweighted scores for PD, 3RUe and 3Rum for a baseline and a redesigned version of the EEE, respectively.

The second step is to estimate the lifetime of the $EEE(LT_{EEE,k})$. The third step is to estimate how much the worst criterion score (i.e., Margin of Improvement $(MI) = 4$ for e.g. $PD1$, $MI = 4$ for e.g. $3RUe1$ etc.) individually in each criteria group (CG) would reduce the lifetime of the EEE resulting in so called individual lifetime reduction factors ($LTRF_{CG,i,j,n}$, see Eq. (1)). The forth step is to multiply all $LTRF$ within each criteria group (e.g. $i = PD$) to arrive at a new number of lifetime units (larger than one) ($ALTRS_{CG,i}$, see Eq. (2)) which the EEE needs per lifetime for each group ($U_{EEE,i,k}$, see Eq. (3)). The relation between the new number of lifetime units (baseline is 1 for all) is the basis for the AHP weighting factors for the Groups.

$$LTRF_{CG,i,j,n} = \frac{LT_{EEE,k} - L_{CG,i,j,n}}{LT_{EEE,k}}, \tag{1}$$

$$ALTRS_{CG,i} = LTRF_{CGi,j,1} \times LTRF_{CGi,j,2} \times LTRF_{CGi,j,3} \times ...LTRF_{CGi,j,n}, \tag{2}$$

$$U_{EEE,i,k} = \frac{1}{ALTRS_{CG,i}}, \tag{3}$$

where
$U_{EEE,i,k}$ = units of EEE of generation k required during EEE lifetime for Criteria Group i,
$ALTRS_{CG,i}$ = accumulated lifetime reduction score for Criteria Group i,
$LTRF_{CG,i,j,n}$ = lifetime reduction factor n for Criteria Group i and Criterion j,

$LT_{EEE,k}$ = Lifetime EEE generation k, years,
$LTR_{CGi,j}$ = lifetime reduction for Criteria Group i and Criterion type j, years,
i = Criteria Group type. PD, 3RUe, 3RUm,
j = Criterion type,
n = number of criteria in Criteria Group $1, 2, 3, ..., n$,
k = EEE generation, e.g. baseline and redesigned.

Table 1. Estimation of lifetime reduction and lifetime reduction factors for different criteria.

		Electronic product $(EEE)(LT_{EEE,k} = 5years)$		
Group (CG)	**Code**	**MI**	**Lifetime reduction (years),** $LTR_{CGi,j}$	$LTRF_{CGi,j}$
Product Durability	PD1	4	1	(5-1)/5=0.8
	PD2	4	0.05	0.99
	PD3	4	2.5	0.5
	PD4	4	2.5	0.5
	PD5	Not applicable	n.a	No. battery
	PD6	4	1	0.8
Ability to Recycle, Repair, Reuse upgrade -equipment level	3RUe1	4	1	0.98
	3RUe2	4	0.1	0.98
	3RUe3	4	0.1	1
	3RUe4	4	0	0.98
	3RUe5	4	0.1	1
	3RUe6	4	0	1
	3RUe7	4	0	1
	3RUe8	4	0	1
	3RUe9	4	0	1
Ability to Recycle, Repair, Reuse upgrade-manufacturer level	3RUm1	4	1	0.8
	3RUm2	4	2.5	0.5
	3RUm3	4	0.1	0.98
	3RUm4	4	1	0.8
	3RUm5	4	0	1
	3RUm6	4	0	1

Very few EEE would score $MI = 4$ for all criteria but it is applied here to predict the effect on lifetime. As shown in Table 1, for $MI = 4$ in PD3 it is assumed that without maintenance infrastructure and availability of wear-out parts the lifetime of the EEE would be reduced 50%. Table 2 shows the $ALTRS_{CG,i}$ and resulting $U_{EEE,i,k}$ and AHP weights (w).

Table 2. Accumulated lifetime reduction, units per lifetime and weights for Electronic Product (EEE).

i	$ALTRS_{CG,i}$	$U_{EEE,i,k}$	Relative	AHP Weights (w)
PD	0.158	6.31	1.00	0.6
3RUe	0.943	1.06	0.17	0.1
3RUm	0.313	3.19	0.51	0.3

From Table 1 it is clear that a very low robustness $(PD4)$ and providing no maintenance (PD3) reduce the lifetime much more than 3Rue and 3RUm criteria, except for non availability of spare parts $(3RUm2)$. Observe that the estimation of lifetime reduction is done for the worst possible design ($MI = 4$ for all applicable criteria) of EEE.

Table 3. Explanation of codes for sub-criteria within each group.

Code	Explanation
PD1	Software and data support
PD2	Scratch resistance
PD3	Maintenance support
PD4	Robustness
PD5	Battery for portable ICT goods
PD6	Data security
3RUe1	Fasteners and connectors
3RUe2	Diagnostic support
3RUe3	Material recycling compatibility
3RUe4	Disassembly depth
3RUe5	Recycled/renewable plastics
3RUe6	Material identification
3RUe7	Hazardous substances
3RUe8	Critical Raw Materials
3RUe9	Packaging recycling
3RUm1	Service offered by manufacturer
3RUm2	Spare parts distribution
3RUm3	Spare parts availability
3RUm4	Disassembly information
3RUm5	Collection and recycling programmes
3RUm6	Environmental footprint assessment knowledge available to improve the equipment material efficiency

4. L.1023 scores for Electronics product

In this research a baseline (Table 4) and a redesigned EEE (Table 5) are evaluated with the L.1023 standard.

Table 4. Baseline design of Electronic product (EEE) unweighted circularity scores

		EEE (baseline)			**12/18/2021**
Circularity Group (CG)	Code	Margin of improvement(MI)	Relevance (R)	Circularity Score (CS)	Average score
Product Durability	PD1	2	3	53	55
	PD2	2	3	53	
	PD3	3	3	27	
	PD4	1	3	86	
	PD5	0	0	0	
	PD6	2	3	53	
Ability to Recycle, Repair Reuse, upgrade - equipment level	3RUe1	2	2	48	31
	3RUe2	3	3	27	
	3RUe3	3	3	27	
	3RUe4	2	3	53	
	3RUe5	4	3	14	
	3RUe6	3	3	27	
	3RUe7	3	3	27	
	3RUe8	3	3	27	
	3RUe9	3	3	27	
Ability to Recycle, Repair, Reuse, upgrade -manufacturer level	3RUm1	2	1	45	39
	3RUm2	3	2	32	
	3RUm3	2	1	45	
	3RUm4	3	2	32	
	3RUm5	2	1	45	
	3RUm6	4	1	31	

Table 5. Redesigned Electronic product (EEE) unweighted circularity scores

		EEE (baseline)			**12/18/2021**
Circularity Group (CG)	Code	Margin of improvement(MI)	Relevance (R)	Circularity Score (CS)	Average score
Product Durability	PD1	2	3	53	60
	PD2	2	3	53	
	PD3	1	3	53	
	PD4	0	3	86	
	PD5	2	0	0	
	PD6	2	3	53	
Ability to Recycle, Repair Reuse, upgrade - equipment level	3RUe1	2	2	48	45
	3RUe2	2	3	53	
	3RUe3	3	3	27	
	3RUe4	1	3	86	
	3RUe5	3	3	27	
	3RUe6	2	3	53	
	3RUe7	3	3	27	
	3RUe8	2	3	53	
	3RUe9	3	3	27	
Ability to Recycle, Repair, Reuse, upgrade -manufacturer level	3RUm1	1	1	69	52
	3RUm2	3	2	32	
	3RUm3	2	1	45	
	3RUm4	2	2	48	
	3RUm5	2	1	45	
	3RUm6	1	1	69	

In Table 6, uncertainties are expressed as orders of magnitude. As shown in Table 2, AHP weights are obtained from creating relative weights of $U_{EEE,i}$. The *AHP* application method presented in [18] (§3, Table 4) is applied to the present example of Baseline and Redesigned *EEE* according to Eqs (4)–(26):

$$S_j = \sum_i w_i \times p_{i,j}\,, \tag{4}$$

$$\Delta S_j = \sqrt{\sum_i (w_i \times p_{i,j})^2}\,, \tag{5}$$

$$\Delta lns_{baseline} = \left(\left(\frac{w_{PD} \times \rho_{PD,baseline} \times \Delta\rho_{PD,baseline}}{s_{baseline}}\right)^2 + \left(\frac{w_{3RUe} \times \rho_{3RU,baseline} \times \Delta\rho_{3RUe,baseline}}{s_{baseline}}\right)^2 + \left(\frac{w_{3RUm} \times \rho_{3RU,baseline} \times \Delta\rho_{3RUm,baseline}}{s_{baseline}}\right)^2\right)^{\frac{1}{2}}, \tag{6}$$

$$\Delta lns_{redesigned} = \left(\left(\frac{w_{PD} \times \rho_{PD,redesigned} \times \Delta\rho_{PD,redesigned}}{s_{redesigned}}\right)^2 + \left(\frac{w_{3RUe} \times \rho_{3RUe,redesigned} \times \Delta\rho_{3RUe,redesigned}}{s_{redesigned}}\right)^2 + \left(\frac{w_{3RUm} \times \rho_{3RU,redesigned} \times \Delta\rho_{3RUm,redesigned}}{s_{redesigned}}\right)^2\right)^{\frac{1}{2}}, \tag{7}$$

$$W_{PD} = \frac{6.31}{6.31 + 1.06 + 3.19} = 0.597 \approx 0.6\,, \tag{8}$$

$$W_{3RUe} = \frac{6.31}{6.31 + 1.06 + 3.19} = 0.100 \approx 0.1\,, \tag{9}$$

$$W_{3RUm} = \frac{3.19}{6.31 + 1.06 + 3.19} = 0.302 \approx 0.3\,, \tag{10}$$

$$\rho_{PD,baseline} = \frac{\frac{55}{60}}{1 + \frac{55}{60}} = 0.48\,, \tag{11}$$

$$\rho_{PD,redesigned} = \frac{\frac{55}{60}}{1+\frac{55}{60}} = 0.52\,, \tag{12}$$

$$\rho_{3RUe,baseline} = \frac{\frac{31}{45}}{1+\frac{31}{45}} = 0.41\,, \tag{13}$$

$$\rho_{3RUe,redesigned} = \frac{1/\frac{31}{45}}{1+1/\frac{31}{45}} = 0.59\,, \tag{14}$$

$$\rho_{3RU,baseline} = \frac{\frac{39}{52}}{1+\frac{39}{52}} = 0.43\,, \tag{15}$$

$$\rho_{3RUm,redesigned} = \frac{1/\frac{39}{52}}{1+1/\frac{39}{52}} = 0.57\,, \tag{16}$$

$$s_{baseline} = 0.6 \times 0.48 + 0.1 \times 0.41 + 0.3 \times 0.43 = 0.46\,, \tag{17}$$

$$s_{redesigned} = 0.6 \times 0.52 + 0.1 \times 0.59 + 0.3 \times 0.57 = 0.54\,, \tag{18}$$

$$\Delta ln\rho_{PDbaseline} = \sqrt{(1-0.48)^2 \times (0.04)^2 \times (0.52)^2 \times (0.04)^2} = 0.0296 \approx 0.03\,, \tag{19}$$

$$\Delta ln\rho_{PDredesigned} = \sqrt{(1-0.52)^2 \times (0.04)^2 \times (0.48)^2 \times (0.04)^2} = 0.027 \approx 0.03\,, \tag{20}$$

$$\Delta ln\rho_{3RUe,baseline} = \sqrt{(1-0.41)^2 \times (0.04)^2 \times (0.59)^2 \times (0.04)^2} = 0.0334 \approx 0.03\,, \tag{21}$$

$$\Delta ln\rho_{3R,redesigned} = \sqrt{(1-0.59)^2 \times (0.04)^2 \times (0.41)^2 \times (0.04)^2} = 0.0232 \approx 0.02\,, \tag{22}$$

$$\Delta ln\rho_{3RUm,baseline} = \sqrt{(1-0.43)^2 \times (0.04)^2 \times (0.57)^2 \times (0.04)^2} = 0.0324 \approx 0.03\,, \tag{23}$$

$$\Delta ln\rho_{3RUm,redesigned} = \sqrt{(1-0.57)^2 \times (0.04)^2 \times (0.43)^2 \times (0.04)^2} = 0.0242 \approx 0.02\,, \tag{24}$$

$$\Delta lns_{baseline} = \sqrt{\left(\frac{0.6 \times 0.48 \times 0.03}{0.46}\right)^2 + \left(\frac{0.1 \times 0.41 \times 0.03}{0.46}\right)^2 + \left(\frac{0.3 \times 0.43 \times 0.03}{0.46}\right)^2} = 0.02\,, \tag{25}$$

$$\Delta lns_{redesigned} = \sqrt{\left(\frac{0.6 \times 0.52 \times 0.03}{0.54}\right)^2 + \left(\frac{0.1 \times 0.59 \times 0.02}{0.54}\right)^2 + \left(\frac{0.3 \times 0.57 \times 0.02}{0.54}\right)^2} = 0.02\,, \tag{26}$$

where
s_i = score of alternative j,
w_i = weight of indicator i,
$\rho_{i,j}$ = relative performance of alternative j for indicator i,
Δs_i = uncertainty of score of alternative j,
$\Delta\rho_{i,j}$ = uncertainty of relative performance of alternative j for indicator i,
$\Delta(lns_{baseline})$ = uncertainty of baseline alternative,
$\Delta(lns_{redesigned})$ = uncertainty of redesigned alternative,
W_{PD} = weight of indicator PD,
W_{3RUe} = weight of indicator 3RUe,
W_{3R} = weight of indicator 3RUm,
$\rho_{PD,baseline}$ = relative performance of baseline alternative for PD,
$\rho_{PD,redesigned}$ = relative performance of redesigned alternative for PD,
$\rho_{3R,baseline}$ = relative performance of baseline alternative for 3RUe,
$\rho_{3R,redesigned}$ = relative performance of redesigned alternative for 3RUe,
$\rho_{3RU,baseline}$ = relative performance of baseline alternative for 3RUm,
$\rho_{3RUm,redesigned}$ = relative performance of redesigned alternative for 3RUm,
$s_{baseline}$ = score of baseline alternative,
$s_{redesigned}$ = score of redesigned alternative,
$\Delta(ln\rho_{PD,baseline})$ = uncertainty of relative performance of baseline alternative for PD,
$\Delta(ln\rho_{PD,redesigned})$ = uncertainty of relative performance of redesigned alternative for PD,
$\Delta(ln\rho_{3RUe,baseline})$ = uncertainty of relative performance of baseline alternative for 3RUe,
$\Delta(ln\rho_{3RUe,redesigned})$ = uncertainty of relative performance of redesigned alternative for 3RUe,

$\Delta(ln\rho_{3RUm,baseline})$ = uncertainty of relative performance of baseline alternative for 3RUm,
$\Delta(ln\rho_{3RUm,redesigned})$ = uncertainty of relative performance of redesigned alternative for 3RUm,
$\Delta(lns_{baseline})$ = uncertainty of score of baseline alternative,
$\Delta(lns_{redesigned})$ = uncertainty of score of redesigned alternative.

Table 6. Decision making for L.1023.

Criteria Group (CG)	**Performance**		**Relative Performance**		**Analytical Hierarchy Process (AHP) weights**	**Score**		**t**	**type I error probability**
	Baseline EEE	Redesigned EEE	Baseline IEEE	Redesigned IEEE		Baseline EEE	Redesigned EEE		
Product Durability	55	60	0.48±0.04	0.52±0.04	0.60	0.29±0.03	0.31±0.03	0.98	0.33
Ability to Recycle, Repair, Reuse, upgrade -equipment level	31	45	0.41±0.04	0.59±0.04	0.10	0.04±0.03	0.06±0.02	3.9	0
Ability to Recycle, Repair, Reuse, upgrade -equipment level	39	52	0.43±0.04	0.57±0.04	0.30	0.13±0.03	0.17±0.02	3.1	0
					Total	0.46±0.02	0.54±0.02	2.8	0.006

The type I error probability that the decision-maker's requirement 257 is not met is only 0.6%. The AHP scores 0.46 and 0.54 will later be combined with the PCF score.

Table 7 shows the relative PCF scores for Global Warming Potential during 100 years (GWP100) for the baseline EEE and the individual PCF scores of the EEE with worst case PD, 3RUm and 3Rue criteria. The total carbon score is much higher for the PD worst case scenario compared to 3RUm and 3RUe as more units (6.31) need to be used during EEE lifetime compared to the other two CGs (3.19 and 1.06).

Table 7. Carbon scores for EEE

Scenario	**TOTAL CO2eq. (relative)**	**Manufacturing (%)**	**Use (%)**	**End-of-first-life (%)**
Baseline EEE	100	79.4	21	-0.36
PD	520	96.4	4.0	-0.43
3RUm	274	92.8	7.7	-0.42
3RUe	105	80.4	20	-0.36

In Table 8 the carbon scores of the baseline EEE and redesigned EEE are presented. By using the AHP scores in Table 6 for baseline EEE and redesigned EEE, 0.46 and 0.54, the redesigned EEE eventually uses 0.84 units during 5 years and thereby has a lower CO2e score thanks to the improved circular product design measures. The circular redesign leads to 12% carbon reduction.

5. Discussion

The present research is illuminating the problem of weighting different Circular Economy criteria in the international L.1023 circular scoring standard [1] and the relation to carbon scoring for environmental impact. Effect on lifetime is chosen as basis for the weighting. Effect on recycling rate is another option. The effect on recycling rate of MI=4 may be less pronounced for several criteria than their effect on lifetime.

Table 8. Relative carbon scores for redesigned EEE as effect of changed criteria

Scenario	Total Co_2eq. (relative)	Manufacturing (%)	Use (%)	End of the first life (%)	Number of used EEE units during 5 years	Weighted EEE units used during 5 years	AHP score
Baseline EEE	100	79.4	20.9	-0.36	1	$U_{EEE,i,k} \times$ Weights $=6.31 \times 0.6 + 1.06 \times 0.1$ $+3.16 \times 0.3 = 4.84$	0.46
Redesigned EEE	88	76.6	23.7	-0.34	4.05/4.84=0.84	4.84×0.46/0.54=4.05	0.54
Redesigned EEE with only M=1	68	69.3	31.1	-0.31	2.79/4.84=0.58	4.84×0.37/0.63=2.79	0.63

In any case, the result of the AHP process shows that, when evaluated with weighting for single circularity score, the redesigned EEE scores slightly higher (that is better) than the baseline EEE. Ideally the carbon (and other indicators and single scores) result would also be better for the redesigned EEE than the baseline EEE. This is also demonstrated herein (Table 8) ibn which redesigned is 12% better than baseline. The rationale is that the redesigned EEE would require e.g. fewer EEE units used per lifetime. Likely the improvement of the criteria in Table 3 have helped increase the lifetime and lower the carbon score of the redesigned EEE. Moreover, compared to the baseline EEE, the relative carbon score for a redesigned EEE scoring MI=1 for all sub criteria in L.1023 is around 68 compared to 88 in Table 8 for the mixed MI values of Table 5. This is based on AHP scores of $0.37(\pm 0.02)$ and $0.63(\pm 0.01)$ for baseline and redesigned EEEs, respectively. As not all criteria are highly relevant ($R = 4$), a perfect Circular Score of 100% is not possible for the present example. The relevance (R) may be different for each case and determined by business model and others. The MI on the other hand can be determined objectively.

The uncertainty range for each design alternative's AHP score is assumed to be around 10% or 0.04 orders of magnitude. The uncertainty is judged to be rather small as it is rooted in the "wrong" choice of MI values for some criteria.

A criterion for modular design is missing from L.1023 despite being an important criterion in other circularity scoring methods [3,7]. Obviously a modular design criterion - added to the 3RUe Group with MI=4 in Table 1 - would reduce the lifetime of several EEE and increase the weight of 3RUe [20].

6. Conclusions

Using lifetime reduction, AHP can systematically be used to determine weighting factors for the three criteria groups of L.1023. For a redesign of an EEE product, the change in carbon score due to a change in weighted L.1023 score can be derived.

7. Next steps

Here the assumed effects on product lifetime of hypothesized worst MI levels are investigated for one EEE. Effect on recycling rate is another option. In general, EEE may have several special considerations and several additional criteria (and perhaps criteria groups) will have to be developed for potential updates of L.1023. Systematic uncertainty estimation of the AHP weighted scores for individual criteria groups can be improved. Another outlook is to include further indicators and single scores for full LCA combined with AHP and uncertainty analyses.

Conflicts of Interest: "The author declares no conflict of interest."

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