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VALIDATION OF THE ECO-TRANSFORMITY METHOD

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1. Introduction

The environmental profile of the product and most of the factors that determine environmental performance, quality and costs are defined in the conceptual design phase of the product development process. Effort devoted to developing and selecting the best concept design pays large dividends to the success of the product on the market. Environmental friendliness of the product is one of the many important evaluation criteria to consider. Environmental impact assessment is the most widely used method for determining environmental friendliness of the product. It provides a quantitative and scientifically valid way of representing the influence of products and processes to the environment. Environmental impact assessment can be performed only if appropriate quantitative information about the product and its life cycle is available to product developers. By default, this requirement is fulfilled the earliest in the detail design phase in case of original design concepts, e.g. products without predecessor concepts.

A question arises on how can evaluation of environmental friendliness be performed in conceptual design phase, since information about the product at this phase are mostly qualitative, product key features and embodiments are not finalized and the life cycle of the product is unknown or vaguely defined. There are two main approaches to eco-evaluation in the conceptual design phase: concept evaluation according to environmental criteria and environmental impact approximation.

Environmental criteria implemented in ecodesign methods and tools for conceptual design phase refer to product's attributes that relate to product's environmental impacts (occuring during life cycle), energy consumption, presence of toxic emissions and substances, use of resources, duration of the product's life span, recyclability and dissassembility of the product. According to conventional theories and models of design [Chakrabarti and Blessing 2014], product's life cycle is considered usually after functions of the product, specifications and embodiment solutions are established.

Five environmental criteria specifically developed to support product concept eco-evaluation are the basis for the method proposed in this work. The method is named Eco-transformity (inspired by one of the five eco criteria). Environmental criteria and the method is an upgraded version of the criteria and method described in authors' earlier work [Midžić et al. 2015b]. Hypothesis defined is that eco-evaluation of a particular technical system's functional structure can be managed by assessing properties of operands (energy, material and/or signal) transformed in the technical process [Midžić et al. 2015b]. The idea is to evaluate concepts represented by their functional decompositions according to criteria of operand transformation quality, and for each operand type – energy, material and signal.

Theoretical background of the energy transformity effectiveness criteria [Midžić et al. 2015b] is the emergy theory. According to emergy theorists, quality of different energy forms, materials, human and economic services can be evaluated on a common basis by conversion to a unified form of available

energy - solar emergy [Cai and Olsen 2004]. Emergy is the available energy multiplied by transformity factor of the conversion process [Voora and Thrift 2010]. Odum [1988] defined solar transformity factors of many energy forms (wind kinetic energy, tide energy, Earth crustal heat), resources (coal, fuel, wood) and some other such as human services and information, which resulted in the hierarchy of energy forms. Hierarchy of energy forms includes low and high quality energy forms. According to maximum work principle [Cai and Olsen 2004], energy transformations where low quality energy forms are used up to realize the work potential of high quality energy forms are favourable energy transformations. Energy transformity effectiveness criteria takes into account the type of energy form transformations that are indicated by the functions of the product (for example, electrical to mechanical, electromagnetic to heat, mechanical to acoustic energy) [Midžić et al. 2014].
Second environmental criterion is a minimizing criterion of the total number of energy, material and signal transformations in the functional structure of the product.
The criterion of eco-quality of energy, material and signal waste/emissions corresponds to evaluating secondary effects towards the environment, e.g. output flows of energy, material and signal in the functional structure of the concept. The criterion of the total number of material, energy and signal waste/emissions corresponds to evaluating the number of different output flows of energy, material and signal in the functional structure. Fifth environmental criterion is the number of functions where material changes states (solid, gas, liquid). The change of material state potentially indicates that additional energy is required for the transformation to occur.
Eco-evaluation according to five environmental criteria is enabled by using a decision matrix and the rank-sum rule [Roozenburg and Eekels 1995]. The applicability of the method is demonstrated to verify the performance of the method and the appropriateness of the example problems. The process of building confidence in the method's usefulness includes checking whether the method provides results correctly (effectiveness) and whether the method provides results efficiently.

2. Literature review and related work

Byggeth and Hochschorner [2006] analysed the characteristics of 15 ecodesign methods and tools and characterized them into three groups: environmental impact assessment methods and tools, methods and tools for improvement and methods and tools for comparison. Environmental assessment methods and tools are based on Life Cycle Assessment (LCA). Use of LCA in conceptual design phase is reliant on availability of quantitative data. Evaluation based on environmental impact assessment requires information on embodiment, properties, features and life cycle aspects of the product, which are not explicitly defined in the conceptual design phase [Midžić et al. 2015a]. Due to lack of information, product developers use information from the reference products to draw conclusions about the environmental friendliness of concepts generated in the conceptual phase.
Environmental impact assessment in conceptual design phase can be managed without performing LCA [Bernstein et al. 2010]. Such approaches depend on commonalities between different product systems and the development of repository of reference products containing LCA of reference products. Fitch and Cooper [2005] point out to lack of environmental impact approximation methods that would be appropriate for original design concepts.
Methods and tools for improvement are ecodesign guidelines or checklists. The use of ecodesign guidelines as criteria for evaluation of environmental friendliness of original design concepts is explored in the work of Midžić et al. [2015a]. In the first part of the case study, evaluation criteria were not proposed to the evaluators. A paradoxical situation occurred, known as Arrow's paradox [Franssen 2005]. In the second part of the case study, the evaluators evaluated the same set of concepts, but this time they used ecodesign guidelines as environmental criteria and a datum ranking method [Pugh 1990]. The introduction of eco-evaluation criteria in the second part of the case study has yielded more coherent results. The case study opened new research questions such as: which eco-evaluation criteria would be appropriate for conceptual design phase, how many criteria is an optimal number of criteria and which ranking method is the most suitable. The preferred outcome is managing eco-evaluation and ranking of original product concepts and minimizing the effect of the Arrow's paradox.
Methods and tools for comparison provide comparison among different ecodesign strategies or product solutions in order to identify the best or better ones regarding to environmental criteria. These are

simpler methods and tools than LCA. Eco-evaluation using these methods and tools is intuitive and includes subjective judgement of the evaluator regarding the concepts, their attributes, potential environmental impacts and life cycle of the future product. The level of detail at which product design is represented in conceptual design phase, does not match the level of detail that is needed for performing high-fidelity evaluation according to environmental criteria specified by methods such as LiDS Wheel [Brezet and Hemel 1997]. LiDS Wheel is the typical representative of methods and tools for evaluation of concepts according to environmental criteria. In the study performed by Bernstein et al. [2010], designers were tasked to decide between concepts of alarm clocks that should be redesigned to generate a more environmentally friendly variant. They did so by using LiDS Wheel [Brezet and Hemel 1997] and then the results of LCA of concepts. Results showed very similar environmental impacts for all three alternatives. Even when the results were presented by the LiDS Wheel, environmentally friendlier concept was not obvious.

Bygetth and Horschorner [2006] have analysed ecodesign methods to see which ones can facilitate trade-off situations, since sustainability and environmental criteria are multi-dimensional. Establishing relative weights or importance of environmental criteria in multi-criteria decision making is the main obstacle in establishing overall environmental friendliness of solutions. The relative importance of criteria is bound to impact the assessment of concepts. Bygetth and Horschorner propose to determine qualitatively which criteria are more important, i.e. to establish a rank order of the criteria, so that assignment of criteria weights is not performed provisionally by evaluators. Currently, there are no guidelines on how to rank environmental criteria in order of their relative importance.

3. Methodology

According to Pahl et al. [2007], solutions in early design phases need to be evaluated qualitatively, regarding to costs and qualitatively to yield satisfactory product design. Although quantitative eco-evaluation is equally relevant in early phases, the proposed method is aimed at supporting qualitative eco-evaluation of conceptual designs, e.g. concepts generated in conceptual design phase. These concepts may be original designs differing in working principles, functions and principle solutions.

Validation of ecodesign methods and tools can be based on number of different evaluation criteria. Lindahl and Ekermann [2013] define that ecodesign methods and tools need to be useful, provide help for the user to reach an intended goal, have a clearly defined purpose and measurable results. These methods and tools should not be too complex or time consuming. Methods and tools which are considered to be ecodesign methods and tools prescribe consideration of product's life cycle, either through analysis or according to some criteria of product longevity, reusability and other. Eco-transformity method is by default not an ecodesign method, since it does not implement the life cycle perspective when evaluating product concepts. Due to this limitation, Eco-transformity method cannot be validated in the same way as ecodesign methods.

In need of evaluation of environmental friendliness of early design ideas and solutions, Collado-Ruiz and Ostad-Ahmad-Ghorabi [2010] propose that ideas are developed further and in detail, so that environmental impact assessment could be performed. LCA method will be used to provide insight into environmental impact of the laundry cleaning concepts that have been selected to demonstrate the effectiveness of the Eco-transformity method. In order to perform a more formal validation of the method, the validation of the environmental criteria developed and the method, is based upon the Validation Square [Seepersad et al. 2006], a framework for validating methods in engineering design.

4. Eco-transformity method and application

The Eco-transformity method facilitates eco-evaluation process in conceptual design phase. It is based on five environmental criteria and a rank-sum rule.

4.1 Environmental criteria

Eco-transformity method comprises of five environmental criteria which are based on adopted concepts of energy transformation quality [Odum 1988], [Midžić et al. 2014], and waste management hierarchy [Midžić et al. 2015b].

4.1.1 Energy transformity effectiveness of energy and signal transformations

Odum [1988] pointed out that in all processes a large amount of low-quality energy must be dissipated in order to generate a smaller amount of high-quality energy. Low-quality energy forms (for example solar energy, photon energy, wind energy) are indicated by the low transformity factors and high-quality energy forms (electrical energy, human services and information) are indicated by high transformity factors [Midžić et al. 2014]. Energy transformity or energy transformation quality is defined as emergy of one type (form) of energy required to make a unit of emergy of another type (energy form). Solar transformity factors represent the solar energy used in the past to make one joule of available energy in the present, and these are used to convert energy flows into emergy values. By calculating the corresponding solar transformity factor of energy flows into equivalents of solar energy units, a general energy-based hierarchy of energy forms can be established [Odum 1988]. Odum's solar transformity factors are analysed in the work of Voora and Thrift [2010].

$$\varepsilon_{TR} = TR_O / TR_I = \log(TR_O) - \log(TR_I) \tag{1}$$

In equation (1), ε_{TR} is energy transformity of a particular energy conversion process, TR_O is solar transformity of output energy form and TR_I is solar transformity of input energy form. A_i represents the conceptual solution.

$$S_{\varepsilon_{TR}}(A_i) = \sum_{j=1}^{j=k} \varepsilon_{TR_k}(A_i) \tag{2}$$

In (2), $S_{\varepsilon_{TR}}$ is energy transformity effectiveness which is a sum of all energy transformities of energy transformations indicated in the function structure of the concept. Energy transformity can be defined only for functions of the product indicating that there is a change (or transformation) in the energy form between input energy flow and output energy flow. For some energy forms, energy transformity factors are very large, so all transformity factors are transformed into a logarithmic scale. A table consisting of energy transformity factors and their corresponding input energy forms (TR_I, columns) and output energy forms (TR_O, rows) is illustrated in Figure 1.

TR_I / TR_O	E_{lH}	E_{lCh}	E_{Ou}	E_H	E_{Ch}	E_{Wt}	E_{Me}	E_P	E_K	E_{Oc}	E_A	E_E	E_{Hu}	E_I
E_{lH}	0	1,88	2,56	3,00	3,10	3,20	3,38	3,59	3,66	3,88	3,96	4,15	8,32	11,62
E_{lCh}	-1,88	0	0,69	1,12	1,22	1,32	1,51	1,72	1,79	2,00	2,09	2,28	6,44	9,74
E_{Ou}	-2,56	-0,69	0	0,44	0,53	0,64	0,82	1,03	1,10	1,31	1,40	1,59	5,75	9,06
E_H	-3,00	-1,12	-0,44	0	0,10	0,20	0,38	0,59	0,66	0,88	0,96	1,15	5,32	8,62
E_{Ch}	-3,10	-1,22	-0,53	-0,10	0	0,10	0,29	0,50	0,56	0,78	0,87	1,05	5,22	8,52
E_{Wt}	-3,20	-1,32	-0,64	-0,20	-0,10	0	0,18	0,39	0,46	0,68	0,76	0,95	5,12	8,42
E_{Me}	-3,38	-1,51	-0,82	-0,38	-0,29	-0,18	0	0,21	0,28	0,49	0,58	0,77	4,94	8,24
E_P	-3,59	-1,72	-1,03	-0,59	-0,50	-0,30	-0,21	0	0,07	0,28	0,37	0,56	4,73	8,03
E_K	-3,66	-1,79	-1,10	-0,66	-0,56	-0,46	-0,28	-0,07	0	0,21	0,30	0,49	4,66	7,96
E_{Oc}	-3,88	-2,00	-1,31	-0,88	-0,78	-0,68	-0,49	-0,28	-0,21	0	0,09	0,28	4,44	7,74
E_A	-3,96	-2,09	-1,40	-0,96	-0,87	-0,78	-0,58	-0,37	-0,30	-0,09	0	0,19	4,36	7,66
E_E	-4,15	-2,28	-1,59	-1,15	-1,05	-0,95	-0,77	-0,56	-0,49	-0,28	-0,19	0	4,17	7,47
E_{Hu}	-8,32	-6,44	-5,75	-5,32	-5,22	-5,12	-4,94	-4,73	-4,66	-4,44	-4,36	-4,17	0	3,30
E_I	-11,6	-9,74	-9,06	-8,62	-8,52	-8,42	-8,24	-8,03	-7,96	-7,74	-7,66	-7,47	-3,30	0

E_{lH} - Latent thermal energy, E_{lCh} - Latent chemical energy, foton energy, E_{Ou} - Energy from unconsolidated organic material, E_H - Thermal energy, E_{Ch} - Chemical energy, E_{Wt} - Wave and tide energy, E_{Me} - Mechanical energy, E_P - Potential energy, E_K - Kinetic energy, E_{Oc} - Energy from consolidated organic material, E_A - Energy from consolidated anorganic material, E_E - Electric energy, E_{Hu} - Human power, services, E_I - Information, signal.

Figure 1. Energy transformities of energy and signal transformations (logarithmic scale)

4.1.2 Total number of energy, material and signal transformations

Pahl et al. [2007] define environmentally friendly products as products that save energy by for example minimizing the number of energy conversions. Rath et al. [2011] list guidelines pointing out to energy efficient solutions by minimizing the number of energy conversions and energy transmissions. Here, the second criterion is a minimizing criterion - the total number of energy, material and signal transformations An optimal solution is characterised by high value in energy transformity effectiveness and a low total number of energy, material and signal transformations ($N_{\varepsilon_{TR}}$).

4.1.3 Eco-quality of energy, material and signal waste/emissions

Eco-criterion for evaluating material operand transformations that are non-intended secondary outputs indicated by the functional structure (e.g. waste, pollutants, emissions) is defined according to the waste management hierarchy and levels of waste toxicity degrees and end of life treatment [Midžić et al. 2015b]. A twenty-point scale is selected, since it provides sufficiently fine measurements without being overly precise. The scale is linear and ranges from -10 to +10. Values of zero, +5 and +5 are not specified by default because they represent the limits dividing the scale to more and less prosperous solutions.

$$S_{\varepsilon_{EF}}(A_i) = \sum_{j=1}^{j=k} \varepsilon_{EF_k}(A_i) \tag{3}$$

In equation (3), $S_{\varepsilon_{EF}}$ is the total eco-quality of energy, material and signal waste/emissions. It is a sum of eco-quality of all output flows (ε_{EF}). Value assignment is illustrated in Table 1.

Table 1. Interval scale for evaluation according to ε_{EF} criterion

Value	Eco-quality of energy, material and signal wastes/emissions
10	No waste/emissions
9	Significantly small amount of waste/emissions (low environmental impact)
8	Biodegradeable and eco-compatible renewable resource
7	Waste/emissions are reused or reuse is achievable with less effort
6	Recyclable waste/emissions
4	Waste/emissions recyclable with acceptable modifications
3	Medium bio-compatibility and waste/emissions compostable
2	May be used as biofuels
1	Waste/emissions reuse achievable with small modifications
-1	Reuse without energy retrieval
-2	Waste/emissions of low toxicity - indirect release into the environment
-3	Waste/emissions of low toxicity - direct release into the environment
-4	Waste/emissions release (singificant impacts in one environmental impact category)
-6	Waste/emissions of medium toxicity - indirect release into the environment
-7	Waste/emissions of medium toxicity - direct release into the environment
-8	Waste/emissions release (singificant impacts in more than oneenvironmental impact category)
-9	Waste/emissions of high toxicity
-10	Waste/emissions of high toxicity (highly toxic or radioactive) - direct release into the environment

4.1.4 Total number of material, energy and signal waste/emissions ($N_{\varepsilon_{EF}}$)

While eco-quality of energy, material and signal waste/emissions is a maximizing criterion, total number of material, energy and signal waste/emissions is a minimizing criterion. An optimal solution is characterised by high value of eco-quality of energy, material and signal waste/emissions and low value of the total number of energy, material and signal outputs to the environment potentially resulting in environmental impact.

4.1.5 Number of material state changes (N_{Agr})

Pahl et al. [2007] mention this criterion as indicator of energy intensive transformations. The number of functions where material changes states (solid, gas, liquid) indicates the energy required for the transformation to occur, but also points out to special material properties of embodiment solutions realizing the particular function. Functions that include material flows to change states indicate some special properties of the material of the embodiment solutions realizing the particular function, such as heat resistance or other. These requirements may be a good indicator of environmental impact.

4.2 Rank-sum rule

A quantitative nominal value is assigned to each criterion outcome. This quantitative nominal value indicates a qualitative rank order [Roozenburg Eekels 1996].

4.3 Application of the Eco-transformity method to eco-evaluation of laundry cleaning concepts

The use of Eco-transformity method is demonstrated on the case of comparison of environmental friendliness of laundry cleaning concept variants. Six concepts in total have chosen and their function structures were generated. In concept A, laundry cleaning is enabled by warm water, detergent and mechanical action provided by the machine drum [Midžić et al. 2015b]. The most environmentally unfavourable energy transformations in all concepts analysed in this work is the transformation of information or signal to electrical energy (energy transformity of this conversion is -7,47). Energy transformity of thermal energy to latent thermal energy conversion is -3,00, also a less favourable conversion from one form to the other. Conversions into latent energy form are characteristic to thermal and chemical energy.
The concept B is a similar laundry washing concept and is based on the washing machine concept implementing Samsung EcoBubble™ technology, cool water laundry washes are as effectively as warm water washes, which saves energy [Samsung Electronics Co Ltd. 2015].

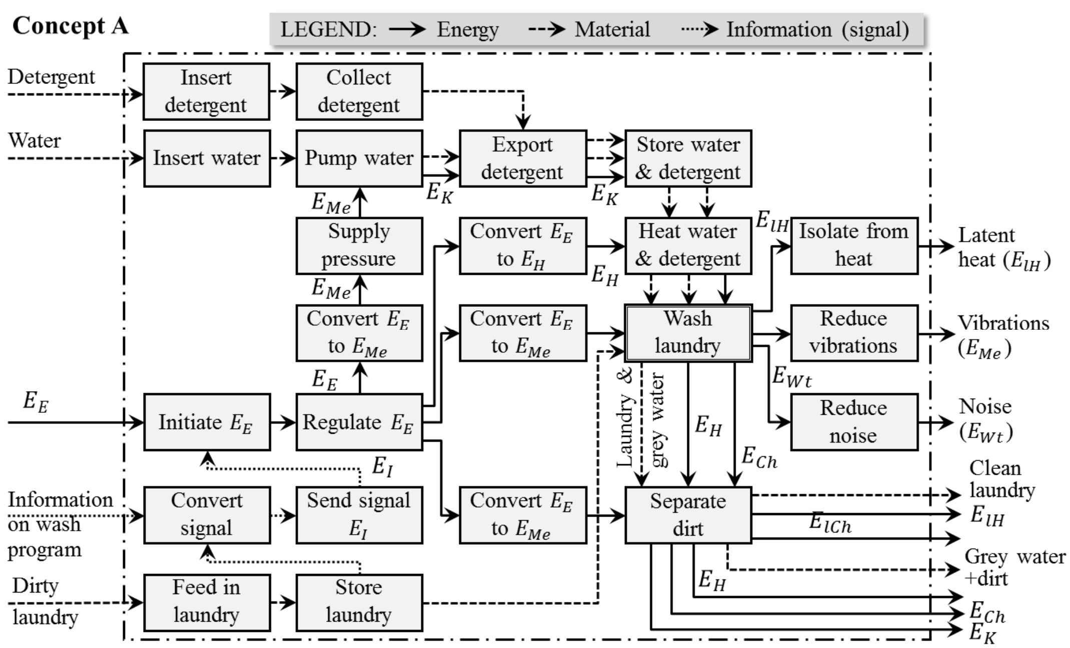

Figure 2. Function structure (concept A)

The concept C is based on the patented ultrasonic textile washing process [Gallego-Juárez et al. 2010]. Separating dirt from the laundry fibres is aided by liquid detergent, water and the cavitation effect produced by ultrasound technology [Midžić et al. 2015b]. Functional structure shows less functions and energy and material flows than in the case of concepts A and B. Since there are no physical effects requiring thermal or latent thermal energy, energy transformity effectiveness of concept C is the best in comparison to the other concepts.

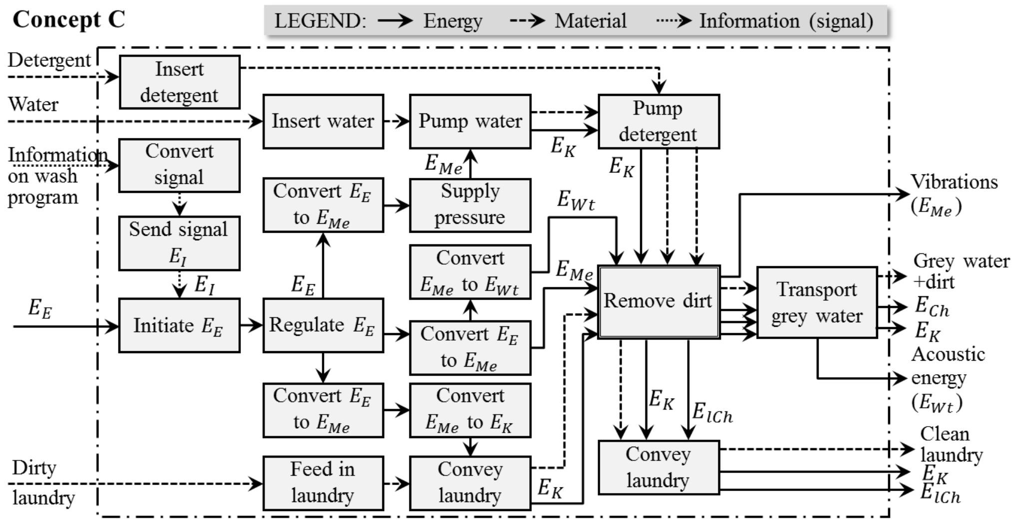

Figure 3. Function structure (concept C)

The concepts D[a] and D[b] are the two variants of dry ice cleaning technology for laundry cleaning application. Dirt from the laundry fibres is removed by using dry ice (carbon dioxide). In the D[a] variant, compressed air is used to propel dry ice pellets into a washing machine drum-like container where laundry is stored. In the D[b] concept, liquid dry ice is used to clean the laundry. After dirt is removed from the fibres by mechanical action, the bath of liquid carbon dioxide is turned into gaseous state and pressurised again for storage. The same carbon dioxide is to be used in the next laundry cleaning cycle [Sutanto 2014].

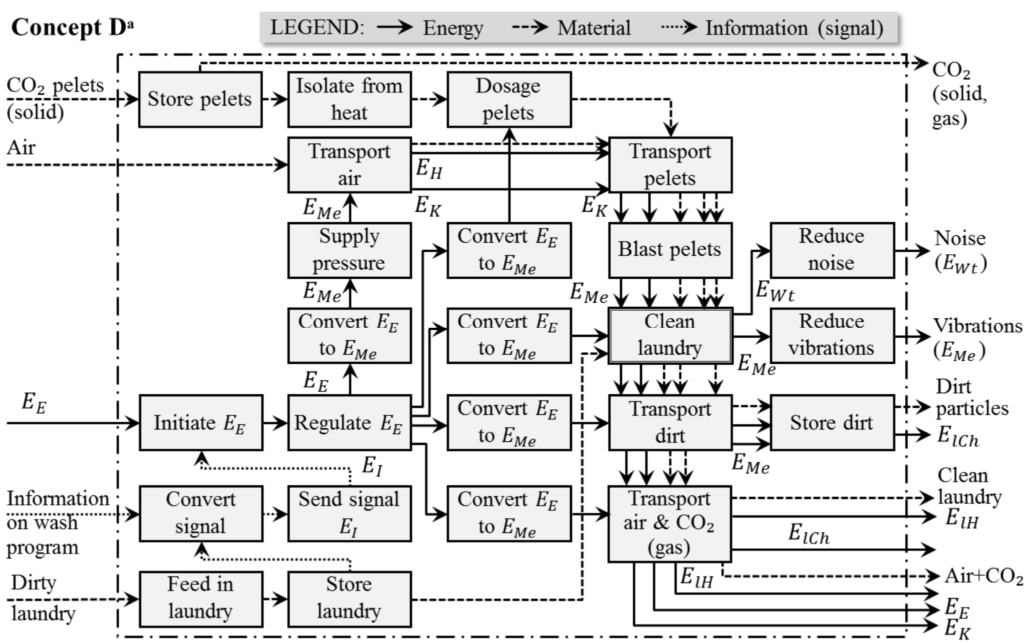

Figure 4. Function structure (concept D[a])

The concept E is a concept of laundry washing with powder detergent and water, on lower temperatures than the concept A. Mechanical action is provided by the rotation of the machine's drum and enhanced by polymer beads [Wells et al. 2015].

Criterion outcomes of decision alternatives are collected in a decision matrix comprised of a set of columns (criteria) and rows (concepts). The results of eco-evaluation of laundry cleaning concepts are summarized in a decision matrix in Table 2.

Table 2. Decision matrix (laundry cleaning concepts)

Con-cepts	Environmental criteria and ranking										
	$S_{\varepsilon_{TR}}$	V_1	$N_{\varepsilon_{TR}}$	V_2	$S_{\varepsilon_{EF}}$	V_3	$N_{\varepsilon_{EF}}$	V_4	N_{Agr}	V_5	V_R
A	-18,55	3	13	1	-7	4	5	2	0	1	10
B	-17,23	2	14	2	5	2	5	2	0	1	9
C	-16,65	1	14	2	-1	3	3	1	0	1	8
D^a	-19,88	4	17	3	-30	6	8	4	2	2	19
D^b	-21,8	5	18	4	-17	5	8	4	3	3	21
E	-21,97	6	17	3	10	1	7	3	0	1	14

V_1 - ranking according to $S_{\varepsilon_{TR}}$ criterion; V_2 - ranking according to $N_{\varepsilon_{TR}}$ criterion; V_3 - ranking according to $S_{\varepsilon_{EF}}$ criterion; V_4 - ranking according to $N_{\varepsilon_{EF}}$ criterion; V_5 - ranking according to N_{Agr} criterion; V_R - sum of ranks.

5. Validation of environmental criteria and Eco-transformity method

Seepersad et al. [2006] describe their validation method (Validation Square) as a process of building confidence in the method's usefulness with respect to its purpose. Example problems of concepts of processes of laundry washing satisfied the requirements for original and innovative concepts (concepts C, D^a, D^b and E), as the purpose of the method is to support eco-evaluation and comparison of original design concepts.

Table 3. Theoretical validation of the method constructs - individually and integrated

Method constructs	Description
Criterion 1	Energy transformity effectiveness criterion is a maximizing criterion.
Criterion 2	Total number of energy, material and signal transformations criterion is a minimizing criterion.
Criterion 3	This criterion is based on the adopted concept of waste hierarchy and evaluating toxicity [Midžić at al. 2015b]. For this criterion, it is convenient to range the scale around zero. Zero is a neutral value. Negative numbers suggest less preferable options. Positive numbers suggest better options.
Criterion 4	Total number of energy, material and signal waste/emissions criterion is a minimizing criterion.
Criterion 5	The number of material state changes criterion is a minimizing criterion.
Decision matrix	Eco-evaluation in conceptual phase is approached as a multicriteria decision-making problem. Selection of preferable concepts, excluding of unsatisfactory concepts and ranking are facilitated by evaluating each concept according to a set of criteria - a process aided by a decision matrix.
Relative importance of criteria	In case of a small number of criteria, radically different results may be expected with just a minor adjustment in criteria weights. In absence of guidelines on assigning criteria weights or how to determine them, criteria are set to be of equal importance.
Rank-sum rule	Ordinal methods like heuristic decision rules, elimination by aspects, new product profiles, the datum method [Pahl et al. 2007], paired comparison, the majority rule, the Copeland rule, the rank-sum rule, the lexicographical rule [Roozenburg and Eekels 1996] and Pugh's concept selection [Pugh 1991] are qualitative evaluation methods. Performance of the method when rank-sum rule is used provided the most satisfactory results.
All elements integrated	Evaluation of the method for processing a decision matrix (rank-sum rule) in combination to five environmental criteria. Absence of any of the method constructs results in incomplete data and non-satisfactory ranking of concepts.

From an industrial perspective, the purpose of the method is typically linked to reducing cost, time or improving quality. In order to provide indicators of quality and effectiveness of the method, outcomes of using Eco-transformity method are compared to results of LCA of concepts. Eco-evaluation of laundry cleaning concepts by using LCA method and Eco-transformity method shows correlation in ranking of the concepts (Figure 5). Eco-evaluation is not consistent in when ranking concepts B and C (within the statistical error of LCA) and concepts D[a] and E (due to assumptions made regarding functions and embodiment solutions of the concepts).

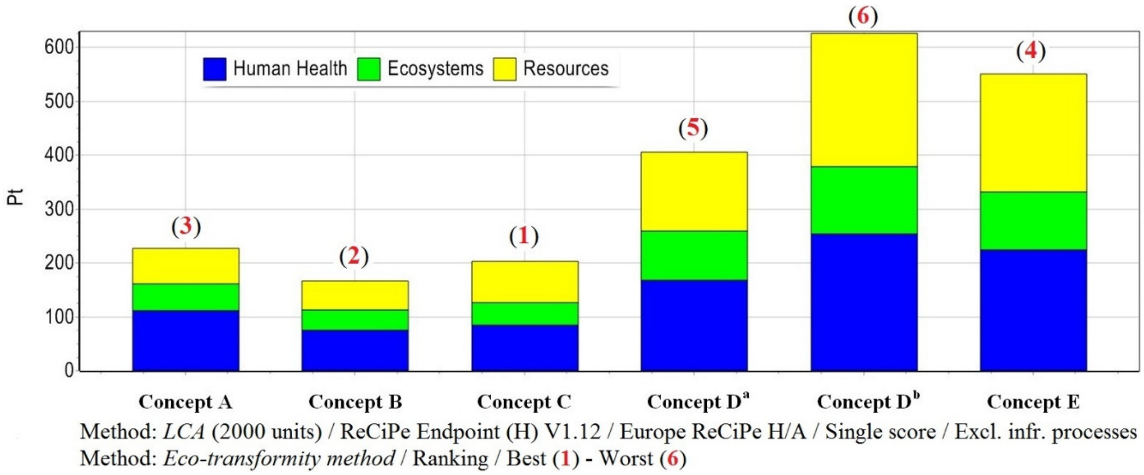

Figure 5. Comparison of results of LCA and Eco-transformity method

LCA of concepts is robust, e.g. assessment is based on assumptions about the life cycles of concepts. Environmental impacts occurring in transport stage and end of life stage of one product or concept are not comparable to environmental impacts occurring in transport stage and end of life stage of another product or concept. Since a number of different scenarios may be generated for those life cycle stages for each concept; each scenario resulting in variant (qualitatively advantageous or disadvantageous) environmental profiles of the future product, life cycle stages transport and end of life are not included in the environmental impact assessment performed.

6. Conclusion

Environmental criteria used in ecodesign methods and tools are not specifically defined to facilitate concept evaluation. Information on concepts or product in general at conceptual phase of product development is not sufficient to precisely define any of the following environmental criteria: energy consumption, toxic substances, environmental impact, recyclability and other. For this to be possible embodiment solutions need to be developed and product's performance in life cycle stages assumed a forehand. According to widely accepted design theories and models of design, embodiment and life cycle design are not explicitly defined and not final in conceptual design phase.

In order to support concept evaluation according to environmental criteria, the method called Eco-transformity is proposed. The purpose of the method is environmental evaluation and ranking of technical system alternatives in the conceptual design phase. Five environmental criteria are developed and they are the basis for evaluation of a set of concepts represented by their functional structures. Validation of the method is based on Validation Square [Seepersad et al. 2006] with the aim to establish method's usefulness with respect to its initial purpose. Method validity is checked by reviewing the individual constructs constituting the method, the method's consistency and the appropriateness of the chosen example problems. The initial purpose of the method is to support eco-evaluation of original design concepts, so the effectiveness of the method is checked on an exemplary type of problem which is eco-evaluation of laundry cleaning concepts. LCA of those concepts is also performed and the results confirm that Eco-transformity method points out to environmentally more and less favourable concepts.

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