DEVELOPMENT OF A SET OF CRITERIA AS AN ECO-DESIGN TOOL FOR EVALUATION OF ENVIRONMENTAL IMPACT OF MATERIAL CHOICE

KRITĒRIJU KOPAS KĀ EKODIZAINA INSTRUMENTA IZSTRĀDE IZVĒLĒTO MATERIĀLU IETEKMES UZ VIDI NOVERTĒŠANAI

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Introduction

Eco-design is a part of the product design process aimed at reducing environmental impacts of the product during its whole lifecycle. Nowadays, the eco-design concept becomes more and more important, and it is also incorporated in the latest legislation developments [1], despite the fact that enterprises, in particular small ones, are hesitant to implement eco-design. There are many tools developed in order to facilitate the implementation of eco-design into real life, however *“eco-design techniques may not have been more widely adopted by businesses because such methods are not necessarily generic and immediately applicable, but instead must include some form of process-specific customisation prior to use”* [2].

Eco-design very often starts with an investigation of the environmental impacts of the current product, and the most comprehensive method for this purpose is Life Cycle Assessment (LCA). The quotation above is true of the LCA – despite the comprehensiveness and scientific soundness of this method, many practitioners avoid using it. Practitioners were asked to choose the most suitable eco-design tools and among 15 tools which support the eco-design process, the LCA placed 14th [2]. The most favourable applications were checklists, eco-ideas' maps, environmental effect analysis and guidelines [2].

In order to promote eco-design in the industry, there is a need for the further development of more practical tools, taking into account scientific findings, but also making them applicable in the product design process. The objective of this paper is to present the main considerations in order to develop a set of criteria for the material choice taking into account LCA studies and available data regarding the environmental performance of materials.

The importance of the material choice: example of LCA findings regarding personal desktop computers

The importance of the material choice can be illustrated with an example of LCA studies. One of the products analysed in several LCA studies is the desktop personal computer in Korea 2006[3], EU 1998 [4], EU 2005 [5], EU 2006 [6], and China 2009 [7]. Each of these studies have chosen a different methodology for the LCA and thus the results are not easy to compare and interpret. One important drawback of the above-mentioned studies is the fact that currently the LCA methodology regarding the impact assessment of chemicals is underdeveloped as only some of the endpoints for human toxicity are considered [6]. Therefore, not all of the above mentioned studies have included the impact category related to chemicals, e.g., EU 1998 [4] has not included human toxicity as an impact category, but have considered the potential effects separately - outside the scope of the LCA.

The results indicate that the major impacts are caused by two aspects - 1) material use and recycling (extraction of materials, processing, recycling, landfilling) and 2) energy use during the use phase. There is a sense to separate reduction of energy use and optimization of the material choice during the product development process, since the real actions lie in separate engineering areas.

Material use causes environmental impact mainly due to the energy consumed during production and processing, as well as due to the resources depleted during extraction, and due to the toxic effects created during the whole lifecycle. Also, depending on the end-of-life scenario and how much of the product can be recycled - the total environmental impact can be decreased.

Table 1.

Aspects of material selection in the environmental product design

Author	Environmental aspects of material selection	Quantifiable criteria
Ashby, Johnson [9]	Eco-attributes: Energy content (MJ/kg) Potential for recycling (high – low)	Partly provided
Eco-design Pilot [10]	<ul style="list-style-type: none"> • Good environmental performance • Avoid (reduce) the use of toxic materials • Prefer renewable raw materials • Prefer recyclable materials • Avoid inseparable composite materials • Avoid raw materials of problematic origin 	Not provided
Luttrupp, Lagerstedt [11]	<ul style="list-style-type: none"> • Do not use toxic substances and utilize closed loops for necessary but toxic substances • Use structural features and high quality materials to minimize weight • Promote repair and upgrading • Promote long life, esp. for products with significant environmental aspects outside of the usage phase • Invest in better materials, surface treatments or structural arrangements to protect products from dirt, corrosion and wear • Prearrange upgrading, repair and recycling • Promote upgrading, repair and recycling by using few, simple, recycled, not blended materials and no alloys • Use as few joining elements as possible, use screws, adhesives, welding, snap fits, geometric locking 	Not provided
Ozoliņš, Geriņš [12]	<ul style="list-style-type: none"> • Nature protection • Environmental pollution during extraction and production of raw materials, production and use of product • Toxicity by use and accidents • Storage safety • Recyclability 	Not provided
Nissen [13]	<ul style="list-style-type: none"> • Toxicity potential • Recyclability • Energy content 	Provided
Ljunberg [14]	<ul style="list-style-type: none"> • Renewable • Recyclability • Durability • Toxicity • Density 	Not provided

System of criteria for sustainable material choice

Screening the literature sources shows that in quite a few studies several aspects for environmentally sound material choice are defined. Some of the authors have developed criteria for particular sectors (building sector [7,8]). Aspects from some research studies are presented in Table 1. The environmental aspects

considered in these research studies are quite different and not easy to assess. From the studies presented in Table 1 only one presents quantifiable criteria [13]. Considering the environmental impacts of the PC desktop unit (see previous chapter), the aspects for environmentally-sound material choice are presented in Figure 1.

Fig.1. Aspects of environmentally-sound material choice

These criteria correspond very well with the work of Nissen [13], which can also be explained by the fact that the study was devoted to the environmental impact of electronic products. A closer look into these aspects – toxic dispersion, energy content and recyclability, and their inter-linkage is presented in the following chapters.

Energy content

Energy content of the raw material is expressed as MJ of the energy necessary to extract and produce one kg of the raw material, and this information can be easily found in literature. Obviously, the total energy content depends on the **amount** of the material required. Shaping and further processing of the material requires some energy as well, but it is usually less than initial production.

Energy content also depends on recyclability, e.g., usually the energy necessary for recycling of the materials is less than the energy used for primary production. Therefore, if the material is recycled, this lowers the total energy demand of the whole system.

Figure 2 represents the energy content of some of the materials in a logarithmic scale. This scale is very convenient for splitting the range into five parts in order

to characterize the energy content from low to very high.

Recyclability

Recyclability depends on various factors:

1. Inherent properties of the material;
2. Design of the final product (% of decrease of inherent recyclability) –the pure technical design also influences recyclability. For example, if the material is easy to separate during dismantling, or the exact opposite – it is very difficult to separate. Currently the sorting and recycling techniques are rapidly developing which make it possible to increase the percentage of recycled material [2];
3. End-of-life scenario (% distribution of the whole product, e.g., the materials contained in the waste streams for recycling, incineration and landfills);
4. Amount of material.

To develop a set of criteria for inherent recyclability properties of the material, an analogous approach to the EU waste management hierarchy [15] can be used (see Figure 3).

Fig.2. Energy content of some of the materials [data from 13]

Fig.3. Waste hierarchy

Based on this analogy, the following scale can be proposed, see Table 2.

Table 2.

Recyclability scale

Value for non-recyclability	Description
Negligible	Reuse of the product or a part of it
Low	Recyclable, the same quality
Moderate	Recyclable, but lower quality
High	Energy recovery, inclusion in unrecyclable materials
Very high	Disposal

Toxic dispersion

The toxicity of the materials depends on the content of toxic substances. Further on, the whole toxic impact depends on the inherent toxicity of the substances, as well as on the exposure patterns:

- the mobility of the substance and partitioning in the environment;
- the strength of binding to the product matrix (e.g. whether the chemical can be washed out from the surface);
- use of the product (how much and in which environmental medium the chemical is released, how much it is directly exposed to the person – user of the product);
- end-of-life scenario (also with regard to occupational health risks).

Various methods exist for the characterization of toxic materials, but each of them has some drawbacks. Unfortunately, the current LCA methodologies regarding the impact assessment of chemicals is insufficiently developed as only some of the endpoints for human toxicity are considered [6, 16] (see examples in Table 3). Therefore, in practical situations, the current LCA results regarding toxic chemicals are insufficient to avoid even known risks and thus the use of additional chemicals risk assessment tools is recommended.

Most often, the existing eco-design guidelines provide lists of undesired substances. Such lists are appreciated by designers but the weakness of such lists is a time delay (the time span between new findings on substance properties and their inclusion in the lists), and only the most commonly used substances and the most hazardous ones are considered during the elaboration of such lists

Table 3.

Aspects of material selection in the environmental product design [6,16]

Method	Ecotoxicity	Human toxicity
CML 2001	<ul style="list-style-type: none"> • Freshwater Aquatic toxicity potential (FAETP) • Marine Aquatic toxicity potential (MAETP) • Terrestrial toxicity potential (MAETP) 	<ul style="list-style-type: none"> • Human toxicity potential (HTP)
Ecoindicator 99	<ul style="list-style-type: none"> • Ecosystem quality, Ecotoxicity 	<ul style="list-style-type: none"> • Human health, Carcinogenic effects • Human health, Respiratory (inorganic) • Human health, Respiratory (organic)
Impact 2002+ (v2.0)	<ul style="list-style-type: none"> • Aquatic ecotoxicity - Midpoint • Terrestrial ecotoxicity - Midpoint 	<ul style="list-style-type: none"> • Carcinogens - Midpoint • Non-carcinogens – Midpoint • Respiratory effects – Midpoint

Other guidelines focus on the classification results of the substances according to the set of criteria in the Directive 67/548/EEC [17] (see overview in Table 4).

All of these instruments are developed for different purposes – the Column model was developed for the evaluation of occupational risks, the TPI - for products, EHS - for choice of environmentally sound substances, the undesired substances in EU Eco-labelled products provide criteria for product development. Most of the tools in Table 4 provide ranking of the substances depending on properties, but eco-label criteria are exclusive: merely providing a list of the properties of

substances, which may not be present in the product. Criteria for the most critical hazard endpoints are also different (see differences between the TPI and Column model), the EHS focuses on PBT-like substances (PBT: persistent, bio-accumulative, and toxic).

As mentioned above, the chemical impact – or so-called “toxic dispersion” - depends on the toxicity of the chemical (inherent properties) and its exposure patterns. Currently, only one tool – EHS - takes into account all of these factors, others only take into account the chemicals’ inherent hazardous properties, and amount.

Table 4.

Toxicity criteria in tools of chemical risk assessment based on chemicals' classification

<div> <div>Chemical risk assessment tool</div> <div>Risks</div> </div>		Dangerous substances in Column model [18]	TPI potential [13]	Environmentally hazardous substances (EHS) [19]	Undesired substances in EU eco-labelled products [20]
Inherent toxicity	Very high	Carc. Cat. I and II: R45, R49 Mut.Cat. I and II: R 46 R26, R27, R28, R32 N & R 50, R51, R53, R54, R55, R56, R57, R58, R59 German water pollution class: WGK 3	Degree: 6-7 R50, R59, R46, R60, R61, R26, R45, R49, R27, R28, R39	1) not readily or inherently degradable, unless $DT_{50} < 60$ days & $\log K_{OW} > 4.5$ if BCF not < 5000 2) not readily or inherently degradable, unless $DT_{50} < 40[60]$ days & $\log K_{OW} > 4.5$ if BCF not < 2000 $LC_{50} \leq 0.1$ (R50) R45, R46, R60, R61	Not allowed: R45, R46, R60, R61 R50; R50/R53; R51/R53 List of very hazardous substances
	High	R23, R24, R25, R35, R29, R31, R43, R42 Repr.Cat.1, Repr.Cat.2, R60, R61 Carc.Cat.3, R40 Mut.Cat.3, R68 (R33) No N, but R52, 53 WGK 2	Degree: 5 R51, R23, R24, R32, R35, R40, R48	1) not readily or inherently degradable, unless $DT_{50} < 40[60]$ days & $\log K_{OW} > 4$ if BCF not < 2000 $LC_{50} \leq 0.1$ (R50) & R45, R46, R60, R61 2) not readily or inherently degradable, unless $DT_{50} < 40[60]$ days $\log K_{OW} > 4$ if BCF not < 500 & $LC_{50} \leq 1$ (R50), R40, R68, R62, R63, R64, R48	
	Medium	R20, R21, R22, R64, R34, R41 Repr.Cat.3, R62, R63 WGK1	Degree: 4-3; R52, R53, R54, R55, R56, R58, R57, R62, R63, R20, R25, R29, R33, R41, R64, R21, R31, R34 R20	not readily but inherently degradable & $\log K_{OW} \geq 3$ if BCF not < 100 $LC_{50} \leq 10$	
	Low	R36, R37, R38 R65, R66, R67 No classification Not water polluting	Degree: 2 R37, R42, R22, R36, R38, R43	Readily degradable $\log K_{OW} < 3$ $LC_{50} \leq 100$	
	Negligible	Harmless substances by experience (e.g. water, sugar,	Degree: 1	Very low: $LC_{50} > 100$	

Chemical risk assessment tool		Dangerous substances in Column model [18]	TPI potential [13]	Environmentally hazardous substances (EHS) [19]	Undesired substances in EU eco-labelled products [20]
Risks		paraffin and similar)			
Other aspects		No	Amount	Amount, mobility, binding to matrix, use conditions, indirect releases	Amount (part 25 g)

The next step of the work will be to develop a criteria system suited for product development, taking into account the most important endpoints and utilizing information on chemicals in the supply chain (e.g., classification and labelling). The criteria system will

also take into consideration that the EU chemicals' classification– labelling system is currently undergoing changes due to the implementation of the GHS system [21].

Fig.4. Set of criteria for environmentally-sound material choice

Conclusion

Based on these considerations, a set of criteria for the material choice can be developed (see Figure 4). This criteria system is based on three main criteria – toxicity, energy, and recyclability, which correspond to the main impact areas of material choice, as concluded from the published LCA studies [3,4,5,6]. These criteria are also linked to each other, e.g., with increasing recyclability one can decrease the energy content, as well as the toxic dispersion. The important innovation in this list of criteria would be that the product design – product structure – and use patterns (including end-of-life scenario) are linked to energy content, recyclability and toxicity.

The next step would be the development of quantifiable values for this criteria system (expressed in five units) and the design of a matrix with interrelations, in order to make it more applicable for the product design

process as a screening tool that is more easily implemented than a complete LCA study. Additionally, such an approach in the evaluation of materials would promote the “cradle to cradle” philosophy.

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**Jana Simanovska, Kārlis Valters, Gatis Bažbauers,
Kritēriju kopas kā ekodizaina instrumenta izstrāde
izvēlēto materiālu ietekmes uz vidi novērtēšanai**

Ekodizains ir daļa no produkta izstrādes procesa. Tā mērķis ir samazināt produkta ietekmi uz vidi visā tā dzīves ciklā. Mūsdienās ekodizaina nozīme aizvien pieaug, un likumdevēji šo pieeju to iestrādā arī jaunākajos likumdošanas aktos. Tai pašā laikā ekodizaina ieviešana rūpniecībā kavējas, jo vairums izstrādāto ekodizaina instrumentu un vadlīniju orientējas uz stratēģisko līmeni, bet trūkst praktisku ieviešanas instrumentu. Lai veicinātu ekodizaina ieviešanu rūpniecībā, nepieciešams izstrādāt vienkāršus instrumentus, kas vadās no jaunākajiem zinātniskajiem atklājumiem un padara tos ieviešamus ražošanā produkta izstrādes procesā. Šī raksta mērķis ir iepazīstināt ar apsvērumiem kritēriju kopas izstrādei materiālu izvēlei, ņemot vērā publicēto dzīves ciklu analīžu rezultātus un datus par materiālu ietekmi uz vidi. Piedāvātā kritēriju kopa balstās uz trim galvenajiem kritērijiem – toksiskumu, reciklējamību (atkārtotas izmantošanas spēju), enerģijas patēriņu, kas atbilst citu zinātnieku publicēto dzīves cikla analīžu pētījumu rezultātiem. Šie kritēriji ir saistīti viens ar otru – palielinot reciklējamību, var samazināt enerģijas patēriņu un toksisku vielu izkliedi. Inovatīva pieeja šajā kritēriju kopā saistās ar to, ka produkta dizains – produkta struktūra un izmantošanas veids ir saistīts ar reciklējamību, toksiskumu un enerģijas patēriņu. Nākošais solis kritēriju sistēmas pilnveidošanā ir kvantificējamu vērtību izstrāde (5 vienības), lai piemērotu šo kritēriju izmantošanu produkta izstrādes procesā, tas ir, radītu instrumentu ātra, lai gan virspusēja, pārskata iegūšanai.

**Jana Simanovska, Kārlis Valters, Gatis Bažbauers,
Development set of criteria as an eco-design tool for the
evaluation of environmental impact of material choice**

Eco-design is part of the product design process aimed at reducing the environmental impacts of products during their entire lifecycle. Nowadays, the eco-design concept becomes more and more important, and it is also incorporated in the latest developments in legislation. However, with regard to the implementation of eco-design, many guidelines and tools still focus on the strategic level, but the practical tools are underdeveloped. In order to promote eco-design in the industry, there is a need for the further development of more practical tools, taking into account the scientific findings, but also making them applicable into a product design process. The intention of this paper is to present major considerations in order to develop a set of criteria for the material choice taking into account LCA studies and available data regarding environmental performance of materials. The

proposed criteria system is based on three main criteria – toxicity, energy, recyclability, which corresponds to the main impact areas of material choice according to findings from the published LCA studies. These criteria are also linked to each other – e.g. with increasing recyclability one can decrease the energy content, as well as the toxic dispersion. The important innovation in this list of criteria would be that the product design – product structure –and use patterns (incl. end of life scenario) is linked to energy content, recyclability and toxicity. The next step would be development of the quantifiable values of this criteria system (expressed in 5 units), in order to make it more applicability of a quick screening tool in the product design process.

**Яна Симановска, Карлис Вальтерс, Гатис Баžбауерс,
Набор критериев как разработка инструментов
экодизайна для оценки влияния на среду выбранных
материалов**

Экодизайн является частью процесса разработки продукта. Его цель – уменьшить влияние всего жизненного цикла продукта на среду. В наши дни значение экодизайна постоянно растёт, и законодатели включают его и в новые законодательные акты. В то же время, внедрение экодизайна в промышленность задерживается, так как большинство разработанных инструментов и руководств экодизайна ориентируется на стратегический уровень, а практических инструментов внедрения не хватает. Чтобы способствовать внедрению экодизайна в промышленность, нужно разработать простые инструменты, которые будут руководствоваться новыми научными открытиями и делать возможным их использование в процессе разработки продуктов.

Цель этой статьи познакомить с соображениями о разработке набора критериев для выбора материалов, принимая во внимание результаты анализов опубликованных жизненных циклов и данные о влиянии материалов на среду. Предложенный набор критериев базируется на трёх основных критериях – токсичность, рециклизация (возможность вторичного использования), затрата энергии, которые соответствуют результатам опубликованных другими учёными исследовательских анализов жизненных циклов. Эти критерии связаны между собой – повышая возможность рециклизации, можно уменьшить затраты энергии и рассеивание токсических веществ. Инновативный подход в наборе критериев связан с тем, что дизайн продукта – структура продукта и способ его использования связан с рециклизацией, токсичностью и расходом энергии. Следующим шагом совершенствования системы критериев является разработка количественных величин (5 единицы) для применения этих критериев в процессе разработки продукта, то есть создание быстрого, хоть и поверхностного, обзора инструментов.