Proceedings of the Estonian Academy of Sciences,
2016, **65**, 3, 297–303
doi: 10.3176/proc.2016.3.11
Available online at www.eap.ee/proceedings

PRODUCT DEVELOPMENT

Design for sustainability approach in product development – a case study using innovative nail polishes developed by a small enterprise

Jana Simanovska* and Zane Grigale-Soročina

Environment, Bioenergetics and Biotechnology Competence Centre, Aizkraukles Str. 339, Riga, LV-1006, Latvia

Received 1 February 2016, revised 31 March 2016, accepted 20 May 2016, available online 1 July 2016

Abstract. This article presents a study on Design for Sustainability (D4S) that we conducted in a small company assessing three innovative formulas of nail polish: conventional nail polish, hybrid polish, and gel polish. In light of the need to reduce environmental pollution, the negative social consequences of the production, and the use of various products, manufacturers are challenged to develop products that are economically feasible, attractive to consumers, cause no harm to workers and consumers, and are safe for the environment. In Europe, small and medium-sized companies (SMEs) produce more than half (by economic value) of all goods. However, are they able to implement D4S and do they have the appropriate tools for it? During our case study, we addressed the question about the existence of a suitable tool for SMEs to apply D4S. As the tool, we used a multi-criterion matrix visualized as a star diagram and adjusted to the needs of a specific company. The newest development in nail coatings – hybrid polish – seems to be the best formula as it provides optimal technical performance and reduces health and environmental impacts. We demonstrated that decision-making is assisted by the use of a simple multi-criterion matrix in the form of a star diagram that integrates environmental and social aspects during the product design phase in a systematic and transparent way.

Key words: consumer, design for sustainability, ecodesign, hazardous substance.

1. INTRODUCTION

Design for Sustainability (D4S) is an emerging trend in product development and has grown as a response to the environmental and social problems caused by production and consumption of products. D4S is an expansion of the ecodesign concept, it considers not only environmental but also social and economic implications as early as during the product development and takes into account all stages of the product life cycle. At the same time, the product has to have excellent functionality and be economically feasible to meet customers' needs.

The product system studied is nail polish systems produced by a small company located in Latvia (Fig. 1). The nail polishes have a specific requirement: the coating has to be stable during the period of use but destroyable at the end of life. This demand makes development of a suitable coating system challenging (Grigale-Sorocina et al., 2015). After use, the worn coating is removed by applying solvents, usually acetone. An innovative coating system should reduce environmental and health impacts when compared to the incumbent products.

Small and medium-sized companies (SMEs) play an essential role in European economies and product turnover: 99.8% of all European-28 enterprises in the non-financial business sector are SMEs, account for 67% of the total employment, and generate 58% of the sector's value added (Muller et al., 2015). Are they able to implement D4S and do they have tools for it?

* Corresponding author, jana.simanovska@me.com

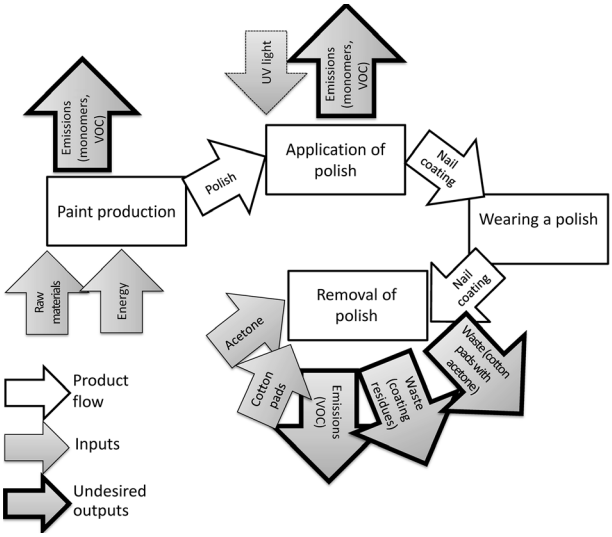

Fig. 1. Nail polish system studied. VOC – volatile organic compounds.

We suggest that a tool for D4S has the same characteristics as tools for ecodesign or 'design for the environment'. This means, paraphrazing Poulikidou and co-authors (Poulikidou et al., 2014), 'any type of systematized aid to incorporating' sustainability 'aspects into the product design and development process'.

It is especially challenging to assess hazardous substances, which is also an important issue for the nail polish industry. The legal requirements (REACH Regulation No 1907/2006, Cosmetics Regulation No 1223/2009) are based on chemical risk assessment and ban the use of such substances and products in which risk is unacceptable. Every company has to comply with relevant legislation. Before market entry, products in the cosmetics industry must undergo cosmetics safety assessment as required by the Cosmetics Regulation No 1223/2009 to determine whether the product is safe for its foreseen use. But this process does not allow for a conclusion regarding whether the new product is better, 'greener', or more sustainable than conventional ones. For a company aiming pro-actively to reduce the use of the most hazardous substances, prioritization is an essential issue. The tools described in the literature include ranking methods utilizing chemical hazard classification (Toxicity Potential Index (TPI) by Nissen (2001), alternative materials assessment by Eisenberg et al. (2013), screening tool for environmentally hazardous substances by Ahrens et al. (2003), and ecodesign method by Simanovska et al. (2012)).

Knight and Jenkins (2009) conclude that practitioners prefer simple ecodesign tools such as guidelines, matrices, and the LiDS wheel rather than complicated analytical methods such as life cycle assessment, which demands more time and resources, being in contradiction to the need for speed required by product development in the industry. However, Knight and Jenkins single out a barrier for adoption of simple methods into industry: they are too generic and prior to use must be adapted to comply with the conditions and needs of the particular company.

The company participating in this study uses star diagrams for decision-making during product development. This methodology has also been used in other studies (Negoescu et al., 2009), which encouraged us to use this approach. It was adjusted to meet the company's needs by incorporating life cycle thinking and by screening hazardous substances in order to demonstrate the performance of three nail polish systems to illustrate the suitability of such tool for decision-making considering design for sustainability.

2. METHOD

2.1. Development of the star diagram approach for the evaluation of products

To develop the D4S method for the company, the product developer cooperated with an environmental engineer and applied the principles of multi-criteria decision methods (Cho, 2003) by formulating targets to be achieved, identifying the essential criterion for each target, and then elaborating a criteria ranking system.

Looking at the product system – nail coating products (see Fig. 1) – in addition to the product (normal nail varnish, UV curing hybrid, and gel polish coating), it is important to take into account the removal of old nail polish, which is usually done with a cotton pad soaked in acetone. All of the nail coating products investigated also contain substances toxic to the aquatic environment, but, according to their type of use, their transport to the aquatic environment is virtually impossible, therefore we did not explore this issue further.

We formulated the following five objectives for the criteria system:

- ensure the greatest possible durability (customer demand);
- reduce the use of highly toxic substances because they are dangerous to the environment and health;
- reduce the use of fossil oil resources by replacing products based on crude oil with those made from renewable resources;
- reduce occupational acetone exposure during the removal of old nail polish by minimizing the use of acetone, which can cause respiratory tract irritation;
- reduce the exposure of consumers' nails to acetone during nail coating removal by shortening the contact time of nail surface with acetone to avoid degreasing effects to the nail surface.

Thus, we identified five criteria for describing our targets:

- durability,
- non-toxicity,
- renewable resources,
- occupational exposure to acetone,
- exposure of consumers' nails to acetone.

For the evaluation of toxicity, we modified ranking tables from previous studies (Simanovska et al., 2012). This system grades hazards of chemicals based on potential long-term effects and content in the material (Table 1).

To describe durability, renewable resources, occupational and consumer exposure, we elaborated the worst and the best case scenario with five levels of impact (Table 2). We did it using our experience and previous data on similar product systems and assuming similarity of the amount of product used per one manicure in all three cases.

Non-toxic and renewable resources were assessed using information on the composition of the products and the information on the ingredients as provided by producers but cross-checked with the EU classification and labelling inventory. The wear time was determined using the method of the producers of the products evaluated here (time when at least 5% of the coverage is lost or damaged, visually determined by the person who tested the quality of the coverage).

2.2. Products studied

- Conventional polish is the typical nail coating formula where the coating is building due to the evaporation of the solvents. For one manicure (10 nails) usually 0.5 g of a product is used. The operator removes the worn coating with acetone using a cotton pad soaked in acetone for a short-time contact.
- Gel polish is a system where the film forms due to the polymerization of monomers and oligomers; a photoinitiator facilitated with an UV light is used. The operator removes the worn coating with a cotton pad soaked in acetone; the contact time is long (10 min).
- Hybrid polish is a system where the film forms because of the evaporation of the solvent and polymerization of copolymers facilitated by visible light. The operator removes the worn coating using a cotton pad soaked in acetone with medium contact time.

Tables 3–5 provide an overview of the ingredients of the products.

Table 1. Ranking regarding presence of substances toxic to human health in product

Hazard characterization	GHS hazard statements according to Regulation (EC) No 1272/2008, EDS categories (EDS priority list)	Ranking based on concentration		
		>0.1	>1	>10
Not classified		5	5	5
Classified hazardous to human health	H300, H301, H302, H310, H311, H312, H330, H331, H332, H314, H315, H318, H319, H335, H336, H304	4	4	3
Sensitizers (skin), STOST cat 2	H317, H373	4	3	2
Sensitizers (inhalation), STOST cat 1	H334, H372	3	2	1
EDS cat 3, CMR cat 2	EDS cat 3, H341, H351, H361, H362	2	1	1
EDS cat 1, 2, CMR cat 1	EDS cat 1, 2, H340, H350, H360	1	1	1
Ranking of impact and criteria value	Desired: 5 Undesired: 1			

Abbreviations:
EDS – endocrine disrupting substances;
CMR – cancerogenic, mutagenic, reprotoxic;
STOST – specific target organ/systemic toxicity;
GHS – Globally Harmonized System of Classification and Labelling of Chemicals.

Table 2. Ranking table for the assessment of the products

Rank	Amount of acetone evaporating during removal of old coating per one manicure, g	Wear time, days	Content of renewables, %	Contact time of nail with acetone during removal of old coating per one manicure, min
5	<0.5	>20	>50	<0.5
4	>0.5 >1	<20 >15	<50 >25	0.5–1
3	>1 >2.5	<15 >10	<25 >10	1–5
2	>2.5 >5	<10 >5	<10 >5	5–10
1	>5	<5 >1	<5	>10

Table 3. Information about products: gel polish ingredients

Function	INCI[a] name	CAS number[b]	Classification under Regulation (EC) No 1272/2008 given by producer	Concentration, % by weight
Film forming	Urethane dimethacrylate	72869-86-4	H317	60–70
Film forming	Tetrahydrofurfuryl Methacrylate	2455-24-5	H315, H319, H335	20–30
UV absorber	Ethyl trimethylbenzoyl phenylphosphinate	84434-11-7	Not classified	1.0–5.0
Bulking, opacifying Viscosity controlling	Silica	7631-86-9/ 112945-52-5/ 60676-86-0	H315, H319, H335	1.0–5.0
Stabilizer for monomers	BHT	128-37-0	Not classified	<1
Cosmetic colourant			Not shown due to high variety	<1

[a] International Nomenclature of Cosmetic Ingredients.
[b] Chemical Abstracts Service Registry Number.

Table 4. Information about products: hybrid polish ingredients

Function	INCI[a] name	CAS number[b]	Classification under Regulation (EC) No 1272/2008 given by producer	Concentration, % by weight
Solvent	Ethyl acetate	141-78-6	H225, H319, H336	25–50
Film forming	Cellulose acetate butyrate	9004-36-8	Not classified	15–25
Solvent	Butyl acetate	123-86-4	H226, H336	10–25
Solvent	Isopropyl alcohol	67-63-0	H225, H319, H336	10–25
Plasticizer	Acetyl tributyl citrate	77-90-7	Not classified	1–5
Film forming	Adipic acid/neopentyl glycol/trimellitic anhydride copolymer	28407-73-0	Not classified	0.1–1
Antistatic	Acrylates copolymer	25133-97-5	Not classified	0.1–1
Binding	Acrylates copolymer	25035-69-2	Not classified	0.1–1
Film forming	Acrylates copolymer	25212-88-8	Not classified	0.1–1
Binding	Hydroxyethyl acrylate/ ipdi/ppg-15 glyceryl ether copolymer	73297-29-7	H319	0.1–1
Plasticizer	Trimethylpentanediyl dibenzoate	68052-23-3	Not classified	0.1–1
Film forming	Ethyl trimethylbenzoyl phenylphosphinate	84434-11-7	H317, H411	0.1–1
Solvent	N-Butyl alcohol	71-36-3	H226, H302, H315, H318, H335, H336	0.001–0.1
Cosmetic colourant			Not checked due to high variety potential	5–0.01

[a] International Nomenclature of Cosmetic Ingredients.
[b] Chemical Abstracts Service Registry Number.

Table 5. Information about products: nail polish ingredients

Function	INCI[a] name	CAS number[b]	Classification under Regulation (EC) No 1272/2008 given by producer	Concentration, % by weight
Solvent	Butyl acetate	123-86-4	H226, H336	25–50
Solvent	Ethyl acetate	141-78-6	H225, H319, H336	25–50
Film forming	Nitrocellulose	9004-70-0	H228	10–25
Plasticizer	Acetyl tributyl citrate	77-90-7	Not classified	5–10
Solvent	Isopropyl alcohol	67-63-0	H225, H319, H336	1–5
Binding, nail conditioning, viscosity controlling	Adipic acid/fumaric acid/tricyclodecane dimethanol copolymer	58891-19-3	Not classified	1–5
Gel forming, viscosity controlling	Stearalkonium hectorite	71011-26-2/ 94891-33-5/ 12691-60-0	Not classified	1–5
Buffering, chelating, masking	Citric acid	77-92-9	H319	<1
Film forming, viscosity controlling	Phthalic anhydridetrimellitic anhydrideglycols copolymer (1,3-isobenzo-furandione, polymer with 5-carboxy-1,3-isobenzofurandione, 1,2-ethanediol and 2,2-dimethyl-1,3-propanediol)	NA	Not classified (information about sensitization in various patients available)	5–10
Cosmetic colourant				5–0.01

[a] International Nomenclature of Cosmetic Ingredients.
[b] Chemical Abstracts Service Registry Number.

3. RESULTS AND DISCUSSION

Evaluation of the product performance by the methodology proposed by the investigators showed that all three products had their strengths and their weaknesses (see Fig. 2). The gel polish outperformed the others for durability but was weaker concerning other criteria. It was the coating with the longest wear time (see Table 6) but with the highest use of acetone (see Table 7).

However, assuming that a customer wants a 21-day long nail coating guaranteed, e.g. as with gel polish, they would repeat the conventional nail polish manicure 4–6 times, but manicure with hybrid polish twice. Moreover, the gel polish is the worst option regarding health, taking into account the amount of acetone and the length of the nail surface in contact with it (see Table 7). However, for this case, we should modify the evaluation system since some assumptions are no longer met.

Table 6. Wear time

Product	Wear time, days
Product 1 – nail polish	3–5
Product 2 – gel polish	14–21
Product 3 – hybrid polish	10

The gel polish contains >50% of a substance classified as sensitizing (hazard statement H317 according to Regulation (EC) No 1272/2008). Therefore, during safety assessment the company assigned an independent laboratory to test safety, including carrying out a patch test. The laboratory concluded that the product was safe for professional use. However, customers have to be informed about the possibility of symptoms of skin sensitization and how to counteract this sensitivity. This product also contains a substance (tetrahydrofurfuryl methacrylate) classified as toxic to reproduction (hazard statement H360 according to Regulation (EC) No 1272/2008) by other manufacturers as documented in the Public Classification and Labelling Inventory (C&L Inventory), but authorities have not yet set a harmonized classification. Thus, the company shall further investigate the proper classification of this substance and shall potentially research whether there are safer alternatives.

The hybrid polish contains >1% of a sensitizing substance (hazard statement H317); therefore during

Table 7. Amounts of acetone used

Product	Contact time with acetone at removal for one nail	Description of procedure	Amount of acetone evaporated (g) if pad used*	
			is disposed in hermetic container	is not disposed in hermetic container
Product 1 – nail polish	10–30 s	1 cotton pad per manicure, total time <5 min	0.3	1.0
Product 2 – gel polish	10–20 min	10 cotton pads per manicure, total time >10 min	4.0	9.7
Product 3 – hybrid polish	30–60 s	2 cotton pads per manicure, total time <10 min	0.6	1.9

* Uptake of acetone per cotton pad: 0.97 g; evaporation time: after 3 min 16.5% of acetone has evaporated, after 5 min 26.8%, after 10 min 41.2%.

cosmetic safety assessment, product safety was tested by a patch test. The conclusion was that the product was safe to use. However, customers should receive information about the risk of skin sensitization and what to do if sensitivity symptoms appear.

Light curing coating systems are usually considered an eco-innovation because they reduce emissions of volatile organics (Wang et al., 2008; Jančovičová et al., 2013). However, this is not the case for nail polishes because at the end of the life phase the removal of worn coating requires much higher amounts of volatile organics (usually acetone) than contained in the initial coating product. In the case of the studied three products, each has its own clients. Therefore, they are going into production, but from the environmental and human health points of view, the hybrid polish seems to be the most promising for further investments.

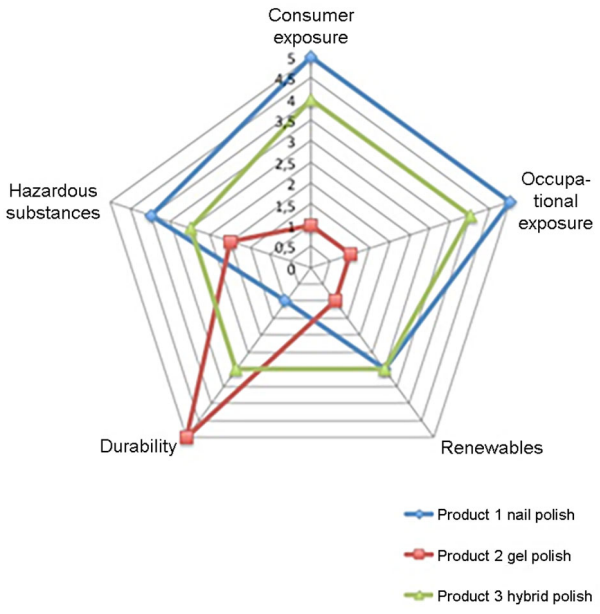

Fig. 2. Performance of the three products (the desired performance is 5, the least desired 1).

The applied method is simple but sufficiently informative for product development because it visualizes the strong and weak points of new products although there is a risk of overlooking some problems. A more systematic tool, e.g. life cycle assessment, could minimize such failure. However, it is not feasible for SMEs because it is expensive. Moreover, this method is also limited to a particular case and has to be adjusted as needed. Such multi-criteria methods are also used for the assessment of other product systems or services where a variety of objectives have to be met, e.g. comparison of results of strategic environmental assessments (Robu et al., 2009), and they can help to make the decision-making process more transparent and understandable.

4. CONCLUSIONS

The newest development in nail coatings – hybrid polish – seems to be the most advantageous formula as it provides optimal technical performance and reduced health and environmental impacts. We demonstrated that the use of the simple multi-criteria matrix in a form of a star diagram helped to perform D4S by integrating environmental and social aspects during the product design phase in a systematic and transparent way.

ACKNOWLEDGEMENTS

We thank the Investment and Development Agency of Latvia (Project No. LKC/2.1.2.1.1/10/01/006, Contract No. L-KC-11-0005) and Kinetics Nail System Ltd. (Latvia) for supporting this research financially.

The publication costs of this article were covered by the Kinetics Nail System Ltd.

REFERENCES

Ahrens, A., Bohm, E., and Heimann, K. 2003 *Guidance for the Use of Environmentally Sound Substances. Part I, Five Steps for the Evaluation of Environmental Risks*. Federal Environmental Agency (Umweltbundesamt), Berlin.

Cho, K. T. 2003. Multicriteria decision methods: an attempt to evaluate and unify. *Math. Comput. Model.*, **37**, 1099–1119.

C&L Inventory, provided by European Chemicals Agency. http://echa.europa.eu/regulations/clp/cl-inventory (accessed 2016-01-11).

EDS priority list. European Commission. http://ec.europa.eu/environment/chemicals/endocrine/strategy/substances_en.htm#priority_list (accessed 2016-01-11).

Eisenberg, D. A, Yu, M., Lam, C. W., Ogunseitan, O. A., and Schoenung, J. M. 2013. Comparative alternative materials assessment to screen toxicity hazards in the life cycle of CIGS thin film photovoltaics. *J. Hazard. Mater.*, **260**, 534–542.

Grigale-Sorocina, Z., Kalnins, M., Simanovska, J., Vindedze, E., Birks, I., and Brazdauska, E. 2015. Additives in UV-activated urethane acrylate polymerization composite coatings. *Proc. Estonian Acad. Sci.*, **64**(1S), 88–93.

Jančovičová, V., Mikula, M., Havlinova, B., and Jakubikova, Z. 2013. Influence of UV-curing conditions on polymerization kinetics and gloss of urethane acrylate coatings. *Progr. Org. Coat.*, **76**(2–3), 432–438.

Knight, P. and Jenkins, J. O. 2009. Adopting and applying eco-design techniques: a practitioners perspective. *J. Clean. Prod.*, **17**(5), 549–558.

Muller, P., Caliandro, C., Peycheva, V., Gagliardi, D., Marzocchi, C., Ramlogan, R., and Cox, D. 2015. *Annual Report on European SMEs 2014/2015, SMEs Start Hiring Again* (Hope, K., ed.). http://ec.europa.eu/growth/smes/business-friendly-environment/performance-review/index_en.htm#annual-report (accessed 2016-01-11).

Negoescu, F., Axinte, E., Nagîţ, G., and Iosub, A. 2009. Innovative solutions creates environmental advantages. *Environ. Eng. Manage. J.*, **8**(5), 1191–1197.

Nissen, N. F. 2001. *Entwicklung eines ökologischen Bewertungsmodells zur Beurteilung elektronischer Systeme*. Ph.D. Thesis, Technical University of Berlin, Department of Electrical Engineering.

Poulikidou, S., Bjorklund, A., and Tyskeng, S. 2014. Empirical study on integration of environmental aspects into product development: processes, requirements and the use of tools in vehicle manufacturing companies in Sweden. *J. Clean. Prod.*, **81**, 34–45.

Regulation (EC) No 1223/2009 of the European Parliament and of the Council of 30 November 2009 on cosmetic products. 2009. *Official Journal of the European Communities*, L342/59, 22.12.2009, Brussels.

Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures. 2008. *Official Journal of the European Communities*, L353/1, 31.12.2008, Brussels.

Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH). 2006. *Official Journal of the European Communities*, L396/1, 30.12.2006, Brussels.

Simanovska, J., Valters, K., Bažbauers, G., and Luttropp, C. 2012. An ecodesign method for reducing the adverse effects of hazardous substances in the product lifecycle. *Latvian Journal of Physics and Technical Sciences*, **49**(3), 57–69.

Wang, F., Hu, J. Q., and Tu, W. P. 2008. Study on microstructure of UV-curable polyurethane acrylate films. *Progr. Org. Coat.*, **62**, 245–250.

Jätkusuutlikkuse saavutamise projekt toote arengu käigus – juhtumiuuring, kasutades väikese ettevõtte väljaarendatud uuendatud küünelakke

Jana Simanovska ja Zane Grigale-Soročina

Jätkusuutlikkuse kavandi uuring viidi läbi väikeses ettevõttes, kus hinnati kolme uuendatud küünelakki: tavaline, hübriid- ja geelküünelakk. Seoses vajadusega vähendada keskkonna saastamist, negatiivseid sotsiaalseid tagajärgi ja mitmesuguste toodete kasutamist nõutakse tehastelt arendada tooteid, mis on majanduslikult kasulikud, tarbijate jaoks atraktiivsed, ei põhjusta töötajatele ega tarbijatele kahju ning on keskkonnaohutud. Väikese ja keskmise suurusega ettevõtted toodavad Euroopas rohkem kui poole kogu kaubast. Kuid kas need ettevõtted on võimelised jätkusuutlikkuse projekti rakendama ja kas neil on selleks sobivad vahendid? Juhtumiuuringu käigus esitasime küsimuse sobilike vahendite kohta, et rakendada jätkusuutlikkuse kavandit väikesele ja keskmise suurusega ettevõttele. Me kasutasime multikriteeriumimaatriksit tärndiagrammina ja kohandasime selle ettevõtte erivajadusele. Hübriidlakk kui uusim toode tundub parimana, tagades optimaalse tehnilise kasutuse ja vähendades tervise- ning keskkonnamõjusid. Me näitasime, et tavalise multikriteeriumimaatriksi kasutamine tärndiagrammina ja integreeritud keskkondlikud ning sotsiaalsed aspektid toote disaini etapil aitavad õigeid otsuseid teha.