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Supporting ECO-innovation in SMEs by TRIZ Eco-guidelines

Davide Russo[a], Malte Schöfer[b,c], Giacomo Bersano[b]

[a]University of Bergamo, viale Marconi 5, Dalmine 24044, Italy
[b]Active Innovation Management, 7 rue de la Croix Martre, 91873 Palaiseau Cedex
[c]Laboratoire Conception de Produits et Innovation, Arts et MétiersParistech, 151 Boulevard de l'Hôpital 75013 Paris

Abstract

An Eco-Design methodology based on two abridged Life Cycle Assessment tools (eVerdEE [1] developed by ENEA [2] and the French Standard NF 01-005) plus TRIZ [3] Eco-guidelines is presented. This method is one of the outputs of the European project REMake [4] (started September 2009 ended December 2012), which had the goal of developing and testing new approaches for eco-innovation, recycling and material consumption for manufacturing small and medium sized enterprises (SMEs). The number of SMEs involved in the project has been around 250, in six countries.
The proposed method consists of a preliminary scanning of a given product or process in order to disclose all the material involved and the energy flows, and to assess their environmental impact by means of a simplified Life Cycle Assessment (LCA) approach and the related indexes. The "hot spots" of the product or process are then identified by adding a brand new index called "IFR (Ideal Final Result) index", conceived from the TRIZ "Ideal System" concept [5], to classical LCA criteria.
Once the hot points are identified, a set of over 300 TRIZ based eco-design guidelines [6, 7] are selectively introduced to develop design variants to the given system with the aim of providing a lower global environmental impact. An in-depth explanation about ECO guideline implementation is given, together with a case study concerning a manufacturer of machine tools.

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1. Introduction

In previous works [3, 6, 7] a method combining an assessment tool based on a abridged Life Cycle Assessment (LCA) and an eco-innovation method (TRIZ Eco-Guidelines) was presented with case study for industrial process. After

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further experimentation with SMEs, the approach has been further optimized, in order to meet their specific requirements for innovation, namely:
- To be user friendly even with limited knowledge in LCA and Eco-design
- To be economic and quick
- To provide easy-to-understand outcomes and data representation
- To provide problem-based improvement heuristics
- To feature examples communicating strategies and results in a simple and powerful way.

In the following paragraph the improved method is described, with a case study on a complex mechanical product.

2. Drawbacks of existing eco-innovation approaches

2.1. Life cycle assessment

Performing a state of the art analysis on current existing methods for eco-design, Life Cycle Thinking (LCT) and LCA are recommended best practice for industries, but their penetration is still weak.
Amongst the causes of this poor penetration, some authors indicate complexity [8]. This fact is strongly limiting the adoption of LCA in small and medium sized enterprises (SMEs).
Although the interest in LCA grew rapidly during the 1990s, and a strong development and harmonization has occurred [9], many authors identified some weaknesses in the LCA approach, hoping for its further developments [10] [11] [12].
Therefore, there is a need for simplified methods that involve less cost, time and effort, but yet provide similar results [12].
Specific simplified (or abridged or streamlined) LCA methods have thus been developed [12] [13] [14] [15] and different depth levels of LCA analysis were defined [15]. For the purpose of application of LCA is SMEs, in the REMake project various available and free LCA tools were analyzed and Everdee developed by ENEA was selected for this approach.
Even if these improvements have increased the ease of use, nevertheless the interpretation of results demands yet people skilled in the art. Moreover, in eco-design it is a common practice to under-evaluate the role of "resources" in TRIZ terms; actually, most methods focus only on materials and energy and this with quite a superficial attitude. For instance the "companies' guidelines" for the choice of material are limited to a simple classification that goes from good materials to be used at will to awful materials not to be taken into account [1]. More generally, existing methods are very effective in the assessment phase or in the improvement phase, but not in both.
The major findings of the methodological benchmarking are the following:

1. The eco-innovation activity is mainly formed of two phases: one on assessment of the existing product and its impact on the environment, and another one of improvement of the product adopting some design guidelines
2. There exists a plethora of LCA methods but most of these methods are too complex and long to meet the requirements of eco-design teams in SMEs.
3. Once a complex LCA done, the support provided to designers by existing Eco-design methods is very weak, not going beyond obvious and generic suggestions.

SME's constraints are an important factor. Considering a rough time scale of the design activity, a detailed quantified LCA analysis could require some months, a simplified LCA could demand a few weeks. This is still too much for most of the SME case studies. This large amount of time and complexity is an important reason that prevents SME from adopting these approaches.
Furthermore, for a new product at an early design stage, when modifications have the highest potential impact on environmental footprint, quantifiable data are not available or, at least, not in sufficient amount. Thus, detailed LCA can only occur at later stages, when substantial eco-innovative design modifications are impossible or not economical any more.

2.2. Eco improvement

Despite the apparent benefits of eco-design, it is unclear if these tools are being used and if they have any real effect on the development of products and systems [16]. Indeed some researches indicate that the application of eco-design tools by SMEs is limited [17]. The main reason is their poor level of detail and the scarcity of indications for the implementation of the guidelines. TRIZ methodology has been evaluated as a potential ally for existing eco-design methods. Some TRIZ fundamentals, such as ideality, resources and laws of technical evolution [5], have been re-organized in the form of practical eco-guidelines [1].The goal of the guidelines is not only providing a tool to better understand what element of our system needs an intervention in order to reduce the system's environmental impact. They are also conceived for supporting designers during the improvement of a product, process or service according to the eco-parameters; this is done until the end of the problem solving process, suggesting directions of work, best tools, heuristics and best practices. These guidelines, extracted from TRIZ laws of evolutions [5], have a main theme which is to reduce resource consumption (mainly material and energy) and thus increasing efficiency. This is possible by taking into account the best heuristics and theories of problem solving, and also by taking into account new trends, technologies and best practices in green design.
In the first versions only eight guidelines (as shown in Figure 1), conceived mainly for TRIZ experts, were developed with the aim of improving the initial system in the phase of product use.

GUIDELINES		RULES	
N. Name		N.	Short Description
ASSESSMENT			
G1 System modelling		R1.1	Main Function identification
		R1.2	Physical description
G2 Resource assessment		R2.1	Resources exploitation indexes
		R2.2	Analyze present/past system condition
		R2.3	Identify external resources
INNOVATION			
G3 Resource saving		R3.1	Use IFR concepts
		R3.2	Reduce Energy conversion to zero
		R3.3	Explore other technologies
G4 Components interaction		R4.1	Make the actions resonant
		R4.2	Coordinate Fields
G5 System dynamization		R5.1	Dinamyze the system
G6 System simplification		R6.1	Eliminates useless components
		R6.2	Solve contradictions
G7 External resources exploitation		R7.1	Merge technical systems
		R7.2	Shift to super-system
G8 Fields cooperation		R8.1	Increase S-Field involvement

Fig. 1. Initial framework of TRIZ-based eco-guidelines conceived for the phase of use.

The previous work was then extended to all phases of the product life cycle, and new directions for action were added. The guidelines actually constitute over 330 actions situated at the phases of pre-manufacturing, manufacturing, product use and end of life.
Each phase contains a set of objects to which the guidelines refer. For every object a list of goals to be achieved, opportunely translated in terms of resource abatement, is provided in order to design a better product.
Then, goals can be achieved by eco-design directions/guidelines, that is detailed suggestions dealing with the way the "resource reduction" target can be achieved by specific problem solving paths, often inspired by classical TRIZ approaches and best green practices [17].
The last part of the directions contains examples of applications which shall serve as a trigger to stimulate ideas by analogy.
The first level contains the objects to which the guidelines refer, the second level deals with the kind of resource involved, the third level is a synthesis of the target to be achieved. Collapsible functions are introduced in order to

simplify the navigation within the diagram.
Among all the directions from the group “Guideline # act on packaging in use phase” one of them suggests to reduce the packaging mass. Table 1 shows how the guidelines help the designer to realize this suggestion by indicating several TRIZ-based strategies as well as some examples of best practice.

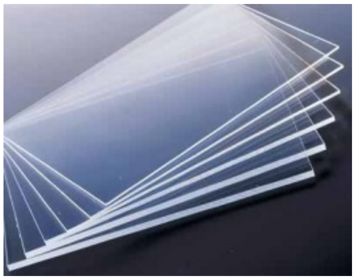
IFR Think about products that don't need packaging (the packaging is already included in the product) **Use packaging mass index** Assessment index: IFR: Zero packaging: 100 ACTUAL: Mass of packaging used **Index**: ((MASS OF PACKED OBJECT - ACTUAL)/ MASS OF PACKED OBJECT)* 100	IFR: absence of packaging, solid inks. The cartridge has been eliminated.  The packaging is already included in the product: Scratch-proof glass 

Fig. 2. Example of guideline for to “*reduce the packaging mass*”.

3. Integrated approach

Therefore, assessment methods and eco-guidelines have been integrated in order to jointly provide a quantitative assessment of product or process ecological impact, and to provide relevant improvement strategies to designers.

3.1. Assessment phase

The first step involves defining the goal of the activity precising what are the expected outcomes, the timing, and the nature of the topic (process or product). In order to describe a given process or product, IDEF0 modeling has been chosen. The IDEF0 language is an updated version of the Structured Analysis and Design Technique (SADT) [18]. IDEF0 describes the specific steps of a process course and the relationships developed. It also records the information flows, resulting from these relationships has been used, specifically set-up for this application. The aim of the modeling phase is to chart all the data of process and products, keeping track of the quality and others metadata and additional information, needed for the use of chosen LCA software, eVerdEE. Employing such a model allows us to show clearly the AS-IS situation; in particular it is easy to define all flows as well as their loops, with the values really used into eVerdEE during the quantitative analysis.
Then IDEF0 modeling is used again after the eVerdEE calculation and it is enriched of specific indicators associated to the flows and the operations inside each phase.
Particularly, in order to highlight the hotspots to improve, a diagram for every considered environmental indicator has to be made, and every flow is mapped with its percentage impact rate on the considered indicator. The environmental indicators and the percentage impact of every flow are provided by the output of eVerdEE. Finally, with the aim to

identify the hotspot, the IFR index is applied to every flow. In order to reduce the environmental impact of the identified hotspot, the guidelines are then applied.
If the analysis concerns an industrial process, then a material flow analysis software can be used [19]; if the analysis concerns a product, the French Standard NF E 01 005 (i.e. MAPECO) is recommended .
MAPECO process is formed of a multiple choice questionnaire, to be filled by the product designer, capable of defining the product environmental profile, indicating in a qualitative way (a scale from 0 to 4) the most impacting phases of a product life cycle:

- Raw materials
- Manufacturing
- Use
- End of life
- Hazardous substances
- Transport
- Packaging

The MAPECO multiple choice questionnaire is formed of qualitative questions concerning the topics of product related raw materials, manufacture, usage, end-of-life/recycling, hazardous substances, transport and packaging. The questions are conceived in a manner that allows also non-LCA-experts to fill in the document. According to his answers, the analyst is guided through an algorithm which leads to the products environmental profile. This profile allows comparing in a qualitative manner the different aspects of the product's environmental aspects. Based on these results the analyst decides on which aspects he or she wants to concentrate his/her design efforts. The typical duration for MAPECO questionnaire method is only few hours.
Then, if there is the need of quantified results and a detailed LCA, the Everdee tool is applied.

3.2. Improvement phase

Once the assessment realized, the inventive activity can be launched, using IFR and eco TRIZ guidelines.

The evaluation of the environmental impact for a substance or a process is connected to two main factors, the quantity of material flows and the energy entering inside the cycle and their specific environmental impact coefficients (eco-indicators). In the literature most available eco-tools mainly focus on assessing how a flux impacts on the environment without any suggestions on where to perform an improvement and how to do it. The novelty of the proposed approach is to introduce an index in order to identify critical areas on which to perform redesign actions. The index is called IFR (Ideal Final Result), as inspired by the homonymous TRIZ tool. IFR indicates what could be the maximal theoretical reduction of each flow. For calculating this index it is necessary to think of the ideality of the system as suggested by TRIZ. In case of energy flow for example IFR is calculated on the base of the following definition:

"The technical system should not only be a suitable power conductor but should also operate with minimal energy losses (such as losses incurred by transformation, production of useless wastes, and withdrawal of energy with ready-made artifact)."

Adopting this index it is possible to associate each flow of energy or substance in input with the maximum potential reduction that can be achieved theoretically. Experimentally the application of the IFR index overturned the initial ranking of the percentage impact rate of the considered fluxes.

This allows highlighting the hotspots on which to act, a diagram for every considered environmental indicator being done, and every flux is mapped with its percentage impact rate on the considered indicator. All these indicators, lead to an immediate reading where identifying the hotspot, which is the flux with the greater potential improvement, is made simple, as the IFR index is applied to every flux.
For eco TRIZ guidelines development, the decomposition on Life cycle phases has been chosen as a foundation; then, these guidelines have been structured following the LCA life phases as structured in eVerdEE software, in order to facilitate future integrations. The phases are, respectively, as follows:

- Pre-manufacturing, i.e. the identification of all elements bought and that will be transformed inside the company later on.
- Manufacturing, i.e. the industrial operation of transforming the components into a product.
- Operation (product use), i.e. the time during which the product operates, including maintenance activity and consumptions.
- End of life, i.e. the recycling part of the product.

Following these guidelines the user is supported to find alternative solutions within the main goal of incoming flow reduction. The goal is to give to the designer all means to limit the use of material and energy flow of the system. They work firstly on system efficiency, on technologies substitution and secondly on flows substitution and optimization.

If the solution is obtained by reducing only existing flows (without introducing any new ones), automatically the reduction of environmental impact is given; if new flows are added to the system, then it is necessary to realize a variant analysis using LCA software in order to verify the global effectiveness of the improvement action.

The overall eco-design process is shown in Fig. 3:

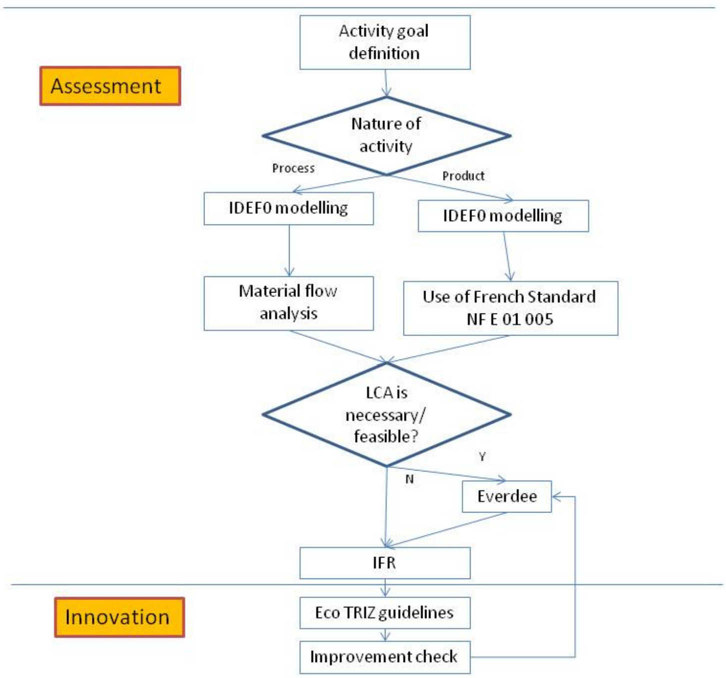


Fig. 3. Proposed Eco-Design approach.

4. Case study

This case study refers to a product innovation. The company is a Turin-based developer and manufacturer of precision mechanics for the automotive sector. During its 80-year history the company specialized in the manufacture of CNC gear shaving and gear honing machines. During the last years the company decided to focus on environmental aspects of industrial production applying ISO 14001: 2004. The system under study is a specific honing machine, named Grono 250, which, according to the company, represents the latest frontier of post-hardening fine finishing

Fig. 4. Picture of the honing machine

The company wanted to improve the preliminary design of its first machine, in order to make it more industrially profitable and to reduce its environmental impact by significantly reducing its energy and material consumption. At the beginning of the study, the company defined the timeline of the analysis, as one month. Considering such short notice and the complexity of the machine (more than 5000 electronic, hydraulic, pneumatic and metallic parts), the detailed LCA analysis was abandoned and MAPECO was chosen.
Going through the method described in figure 3, after a preliminary functional analysis with the support of the IDEF0 the filling of the questionnaire was done jointly with SICMAT Technical Manager, bringing in few hours to the following environmental profile for the cogwheel machine (Figure 5).

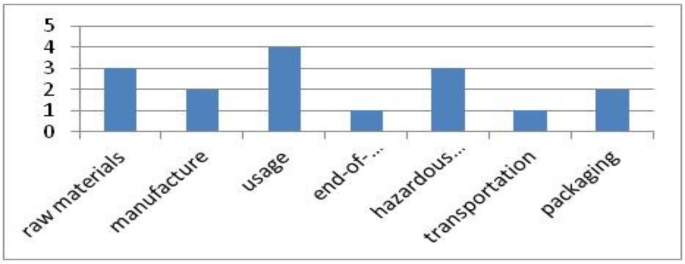


Fig.5. Environmental profile of honing machine.

The analysis showed that the machine's highest environmental impacts are, respectively:

- the raw material necessary for its production
- the consumption of energy and resources during the operation phase
- the toxic materials used (as lubricants and rare materials in electronics).

For this case study, complementary analysis have been done in order to create a Pareto diagram for major consumers in terms of material and energy, which has been used then in working sessions on these topics. In these working sessions the R&D team has started generating some ideas on how to reduce the impact, then has been driven by dedicated eco-TRIZ guidelines selected according to the focus.

Analyzing the honing machine use phase, the facilitator selected the most appropriate guidelines (aimed at reducing the amount of auxiliary materials and components) and used them to stimulate the working group formed of mechanical designers and workers. These specific guidelines suggest as example to:

- modify the system accordingly to the previously identified Idea Final Result,
- explore other technologies dealing with the same improvement problem and benchmark them,
- reduce the energy conversion in the process in order to make auxiliary materials for the purpose of energy

conversion obsolete,

- make the process or specific actions resonant, i.e. replace a continuous action by a periodic or pulsating one,
- dynamize the system, i.e. make the system auto-adaptable to different process conditions and requirements,
- shift to auxiliary materials that are available at low or no added energetic and material cost in the environment, i.e. use or reuse material which has been used for the same other purposes (Fig.6),
- shift from mechanic actions to actions fulfilled by physical or chemical effects…

SUGGESTED TOOLS	EXAMPLES
#7.2 SHIFT TO SUPERSYSTEM Replace auxiliary materials used in the system with materials that are present in environment.	# SHIFT TO SUPERSYSTEM: WASH UP: The idea behind this concept is to make user waste water that coming out of the washing machine. We do use around 150 litres of water for a washing machine, after that … why don't we use it again before the water finally go down the drain? "WashUp" is integrating washing machine with toilet, which mean, it can store wasted water in the toilette-flush tank for us to use when flushing. 

Fig.6. Example of Eco-TRIZ guidelines used in the working sessions.

During a two 2 hours workshop, the group developed 60 ideas respectively to reduce the amount of material required during the manufacture of the gear shaving machine and to reduce the amount of auxiliary materials necessary for the use of the machine.
Throughout a third workshop, five of these ideas were finally chosen to embark on a more exhaustive study.
According to the participants and the responsible, those five ideas will probably lead to reduction of the machines power consumption and mass by 20 % and to a reduction of consumables during product use by 50 %. These major savings in terms of material and energy consumption go along with substantial cost reductions.
According to the Company Technical Manager, the activity also bears value for the design of a comparable machine currently in development.

5. Conclusions

The above mentioned approach has been tested in real case studies in manufacturing SMEs in France and Italy with very good results. It must be noted that using the Ideality concept as "direction" for the design, the solutions point through a radical reduction of resources, and energy, in a more global sustainable development direction. In all cases, quick and effective results have been obtained, both on processes and products, driving the working group quickly on interesting solutions. Another advantage of the approach is to provide designers with the essence of TRIZ heuristics, without a dedicated and long training.

Concerning limitations and future works, the method concerns the development of a rules database derived from a complex theory like TRIZ and its link to assessment tools. It has been tailored in order to fit to the needs of SME actors. Up to now, even if the usefulness for these actors has been proven, enlarged statistical tests would be interesting. To do that, the method is currently taught in some universities, in order to enlarge the base of application.

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