Lean Thinking Process in the Determination of Design Suggestions to Optimize Treatment of WEEE

Anastasia Katsamaki, Nikolaos Bilalis, and Vassilis Dedoussis

Abstract**—**This work proposes a set of actions to assist redesign procedure in existing products of Electric and Electronic Equipment (EEE). The aim is to improve their environmental behavior after their withdrawal in the End-of-Life (EOL) phase. In the beginning data collection takes place. Then follows selection and implementation of the optimal EOL Treatment Strategy (EOL_TS) and its results' evaluation concerning the environment. In parallel, product design characteristics that can be altered are selected based on their significance for the environment in the EOL stage. All results from the previous stages are combined and possible redesign actions are formulated for further examination and afterwards configuration in the design stage. The applied method to perform these tasks is Lean Thinking (LT). At the end, results concerning the application of the proposed method on a distribution transformer are presented.

Keywords**—**End-of-life treatment, Lean thinking, WEEE

I. INTRODUCTION

A major challenge in Wastes of Electrical and Electronic Equipment (WEEE) is to form and apply the optimal in each case EOL_TS in relation with its consequences in the environment besides the cost. Usually applied actions in this direction are to exclude the use of hazardous materials, maximize the use of recycled materials, etc., [1], [3], [6]. These and more possible actions can be scheduled and tested in the product design stage. Redesign process includes a series of actions that aim to improve an existing product. It demands the understanding of market needs, product uses and the desirable features it should have. It is a process not always feasible to be precisely determined right from the beginning of its implementation. In general terms, redesign requires the prior knowledge of product minimum specifications, as well as the evaluation results of product use in the market and the definition of new ideas that could be incorporated in it. The redesign process and the EOL_TS are obviously only a part of the whole product lifecycle, which also includes and other stages as product initial design, product manufacturing and use.

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The simplification of the redesign process of Electrical and Electronic products in relation with the environmental consequences of the applied EOL_TS is a difficult problem since it has to consider many attributes and is affected by several qualitative and quantitative external factors [7], [5]. The LT as a methodology to treat this problem was chosen because it is a different approach in handling complicated situations based on the elimination of useless information and the gradual proposition of corrective actions that can afterwards be reformed or improved in relation with the results taken up to that point. The present work is a part of a general problem that concerns the formulation of a methodology to choose and evaluate the optimal EOL_TS in WEEE and afterwards to improve the results of EOL treatment concerning the environment by redesigning the product.

II. PROBLEM STATEMENT AND ADJUSTMENT IN LEAN THINKING PRINCIPLES

The proposed course of actions includes the examination of two phases of product life cycle, not directly related to each other, product design and product end of life in the frame of the total product life cycle. To ease the analysis performed the whole procedure is divided in five sub-problems.

In the frame of the first field of study (end of life phase):

EOLT_A: Determination and collection of the necessary data for the further stages of analysis.

EOLT_B: Choice of the optimal EOL_TS to be implemented from a list of predetermined possible options.

EOLT_C: EOL_TS application and results' evaluation concerning environment.

In the frame of the second field of study (product design phase):

REDP_A: Determination of characteristics' list from the design stage that can be altered and affect the optimization of EOL product environmental behavior.

REDP_B: Proposals' formulation for the design stage based on the results of stages EOLT_C and REDP_A.

In Fig. 1 these sub-problems are presented in the frame of the whole product life cycle.

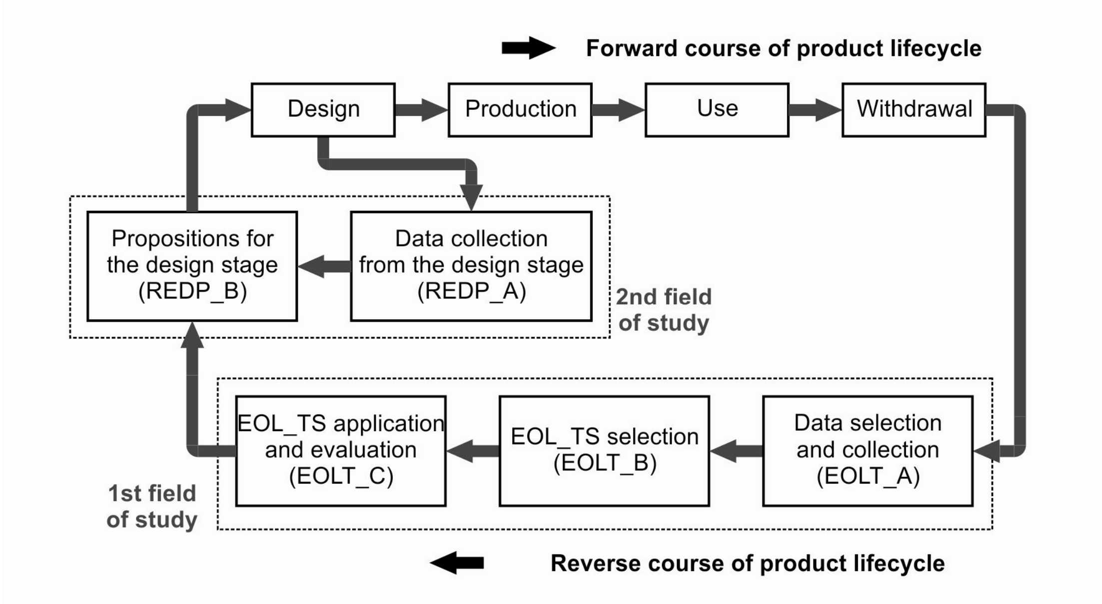

Fig. 1 Graphical presentation of the examined problem

LT is a method that assists the guidance of a system from its initial complicated structure into a simplified one where all answers are revealed with less effort. It does not use specialized methods or different data for the problem under study. It just constitutes a methodology of making an existing situation absolutely comprehensible, therefore suitable ameliorative actions can be proposed, that will improve it [2].

It is based on problem decomposition and search of all factors (visible and no-visible) that can improve the existing procedure by applying the five LT principles as proposed by Womack and Jones, namely, specify value, identify the value stream and eliminate waste, make the value flow, let the customer pull the value process and pursue perfection [8].

The application of LT principles in the present work took place progressively for each stage of analysis. The expected result in each case was to study the whole system from a different point of view and the output to act as an auxiliary tool for the decision maker who treats the EOL product and seeks for redesign possible actions. The adjustment procedure in the LT principles included the following steps:

- Adjustment of all stages of analysis according to the five LT principles.
- Define initial goals, desirable results and adequacy check process in each stage.
- Present possible treatment methods and tools of analysis that could be used for each stage of analysis based on the characteristics of the examined EOL product, the external factors, the existing restrictions and the available means.

Table I presents for each stage a generalized definition of each LT principle.

III. Description of the Proposed Method

Stage EOLT_A: The application of LT principles in EOLT_A stage is a combination of moving forwards and backwards steps. The procedure is based on already known lists of possible data; necessary data for further analysis and list of rules for data inclusion are chosen. Based on these data and the answers to three preliminary questions data that needs to be selected for later search are determined. Then follows the check for data adequacy based on predetermined desirable results. All tasks in stage EOLT_A are presented in Fig. 2.

Stage EOLT_B: The application of LT principles in EOLT_B stage begins from the definition of initial goals and available data. In parallel criteria that will be used for the analysis performed, system restrictions and possible methods of analysis are determined. Finally, the possible EOL_TS that can be selected for implementation are specified. In case the EOL product contains dangerous materials preliminary actions to remove them take place. It follows the selection of the optimal EOL_TS and the check of its adequacy based on the desirable data. Fig. 3 presents analytically all tasks that take place in stage EOLT_B.

Stage EOLT_C: The already known data in this stage of analysis are the results of stages EOLT_A, EOLT_B, the predefined assumptions during the implementation of the optimal EOL_TS and a list of possible parameters for recording the results of EOL_TS concerning the environment. It follows the definition of initial goals for this stage of analysis and the application of the proposed EOL_TS.

TABLE I
LT PRINCIPLES FOR EACH STAGE OF ANALYSIS

EOLT_A & EOLT_B	Value	Positive influence to the environment after product withdrawal.
	Stream Value	Organize necessary tasks to maximize the value.
	Flow	Realize necessary actions considering available data, existing restrictions, minimization of idle times and obstacles' abolishment.
	Pull	Choose and search only necessary data and evaluate only the possible to be applied EOL_TS.
	Perfection	Conduct checks concerning the data chosen to be selected and the determination of possible EOL_TS to be applied for possible errors till the process reaches an acceptable result.
EOLT_C	Value	Degree of positive environmental influence recording to the application of the selected EOL_TS.
	Stream Value	Organize necessary tasks to maximize value.
	Flow	Realize necessary actions considering available data, existing restrictions, minimization of idle times and obstacles' abolishment.
	Pull	Realize necessary disassembly steps in the EOL product and necessary tasks for the application of the chosen EOL_TS. Evaluation of the results that describe the EOL product behavior concerning environment.
	Perfection	Conduct checks certify that the obtained results can evaluate the EOL environmental behavior as well as to conclude whether the results are considered adequately satisfactory.
REDP_A & REDP_B	Value	Coverage degree of design characteristics chosen to be examined with improvement propositions that will benefit the product EOL environmental behavior.
	Stream Value	Organize necessary tasks to maximize the value.
	Flow	Realize certain actions taking under consideration existing restrictions in product characteristics that can be altered.
	Pull	Realize necessary actions for formulating propositions to the product design stage related to the product environmental behavior.
	Perfection	Conduct checks to confirm that propositions for the design characteristics that were chosen have been written down. Also conduct checks to confirm that all results from the application of the chosen EOL_TS that could benefit the analysis performed have been taken under consideration.

Afterwards, the parameters to record the EOL product environmental behavior are determined. The results of the analysis performed are evaluated based on prior already known data of common applied EOL_TS and the limits for the parameters selected. It follows the adequacy check concerning the applied EOL_TS and the level of environmental behavior recording that took place based on the predetermined desirable results. All tasks in stage EOLT_C are presented in Fig. 4.

Stage REDP_A: In parallel with the prior stages of analysis, characteristics from the design phase that can affect the EOL product environmental behavior are searched out. Emphasis is given to design characteristics that can undergo changes and the final product meets the minimum acceptable requirements. Design characteristics are searched for:

- Produced quantities of residues.
- Quantities of WEEE that return in the market.
- Demanded energy.
- Time and depth of disassembly.
- Quantities of each material recovered.
- Dangers included in the EOL stage.

For all design characteristics selected, for further examination, current situation, upper and lower limits and general consequences are recorded. Afterwards, based on the initial goals and the desirable results, adequacy check takes place to verify that all possible design characteristics, that can be examined, have been selected.

Stage REDP_B: Design characteristics from stage REDP_A and parameters that have recorded the EOL product environmental behavior from stage EOLT_C are studied together. The result is to form a table of environmental characteristics and improvement proposals for the design stage based on the initial predetermined goals. The adequacy check examines whether the results of the analysis performed are acceptable and the final propositions are recorded in a results' matrix that is forwarded to the design stage for further examination. All tasks in stage REDP_B are presented in Fig. 5.

IV. APPLICATION OF THE PROPOSED METHODOLOGY IN A DISTRIBUTION TRANSFORMER

A distribution oil transformer 630 kVA, 20/0,4 kV has been used, among other products, for the application of the proposed method.

It is a common type of transformer with expected life time around 30 years. Main parts of it are the core and the windings. For the current case study concerning the core the assumption made is that it is made by stacking layers of thin steel laminations where each lamination is insulated from its neighbors by thin non-conducting layer of insulation to reduce losses. Concerning the windings it is assumed that they are made by copper layers and copper strips with epoxy resins used between layers as conductor insulation mean. For cooling and insulation mineral oil is used.

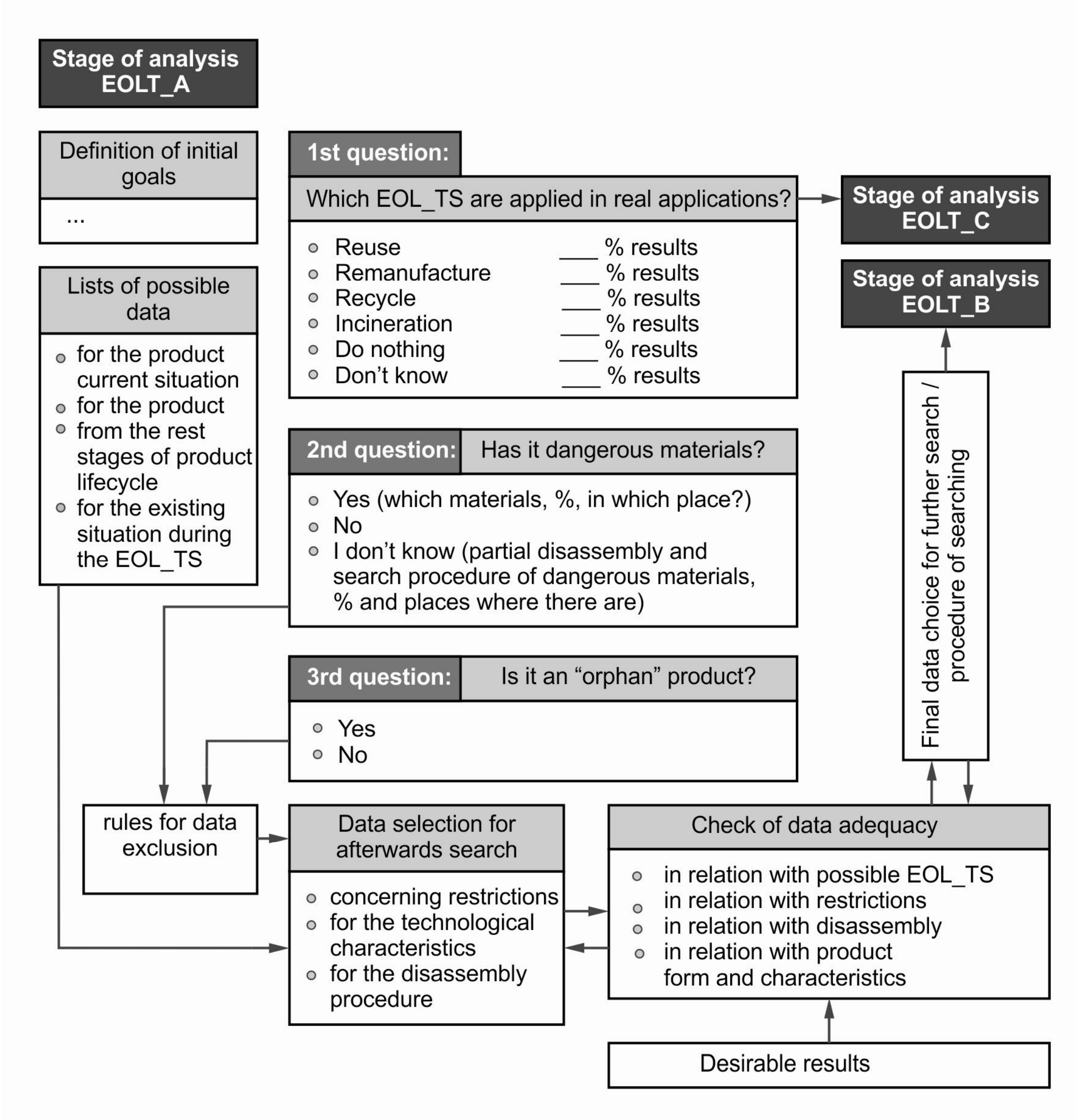

Fig. 2 EOLT_A stage of analysis diagram

The initial filling of the transformer takes place in high air vacuum to prevent humidity and air left in the transformer. Already known data, easily to be selected are the product parts, lists of used materials, types and characteristics of junctions used and assembly charts. Some of the results from the analysis performed till now are [4]:

In stage EOLT_A data concerning system restrictions, product technological characteristics and disassembly procedure where decided to be searched. Also rules for data exclusion were set. Concerning the answers in the preliminary questions the results were:

- It does not contain dangerous materials and the manufacturer is known so it is not an "orphan" product.
- Common used EOL procedure includes removal of mineral oil and other liquids for separate treatment as soon as the product retires and storage in tanks and sell the rest parts in certain companies for further treatment (where the tasks performed can include partial disassembly, isolation of parts that can be reused in secondary markets, isolation of parts that can be recycled or pulverized, sell the EOL product as scrap in other countries, etc.).

In stage EOLT_B possible EOL_TS to be applied were decided to be:

- Product repair and return in the market.
- Repair and upgrade the existing product by substituting certain parts of it.
- Recycle.

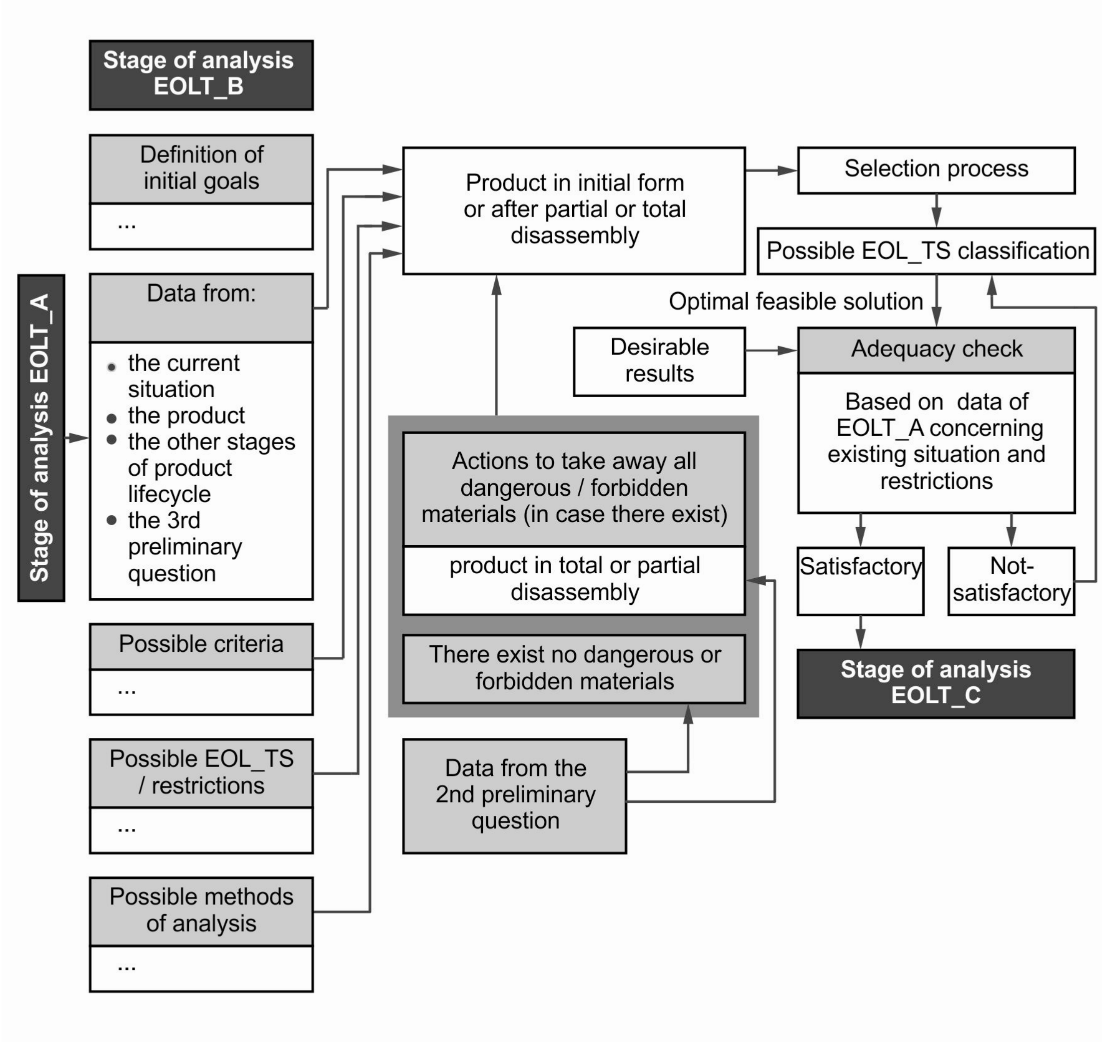

Fig. 3 EOLT_B stage of analysis diagram

The first and second options aim to lengthen the product useful life time. The third option is considered to be the best only in case the life time of the transformer is near the expected life time. Otherwise the other two options are more possible since a transformer is a product of high weight (which means high quantity of scrap to be handled in the EOL phase) and high technological life time (design changes take place in slow rate during product evolution).

In stage EOLT_C the parameters to measure the environmental performance, based on the product characteristics and the prior analysis are:

- Produced residues in liquid form.
- Percentages of materials' recovery that can be recycled.
- Percentages of parts that can be reused.
- Demanded time for the application of the proposed EOL_TS.
- Included danger in the tasks performed during the implementation of the proposed EOL_TS.

As means of evaluation the environmental targets that are used in significance order were the minimization of residues, minimization of time in EOL product handling and minimization of necessary actions in EOL product handling.

In stage REDP_A the design characteristics that have been chosen for further examination are:

- Use of materials with minimum quantities of residues in their final treatment.
- Minimization of transformer dimensions and quantities of used materials.
- Existence of control equipment and schedule of regular service tasks to prevent possible failures.
- Use of parts that can be easily separated and reused.
- Use of materials that can be recycled.
- Use the minimum number of parts.

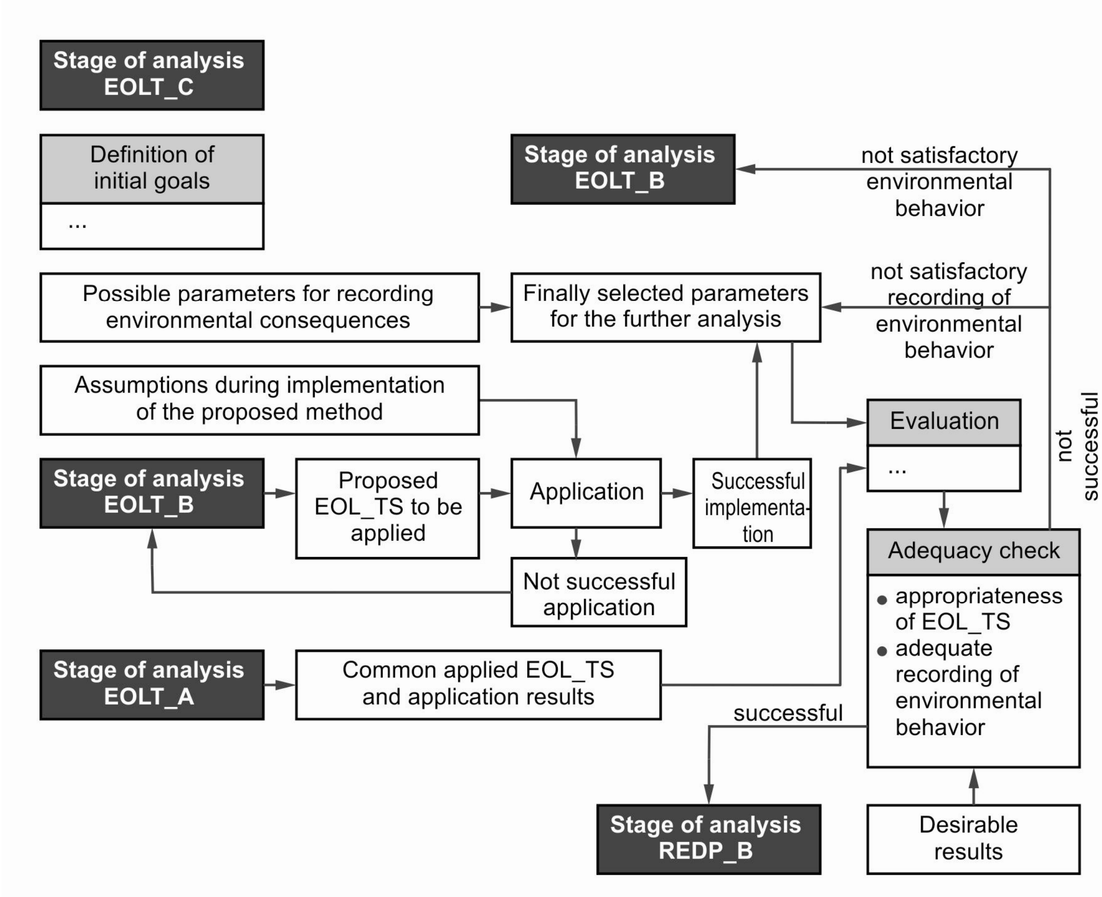

Fig. 4 EOLT_C stage of analysis diagram

- Use the minimum number of junctions.
- Take prevent measures in cases of failure to prevent environmental problems.
- Ease materials' handling that can cause problems in the environment.
- Minimize all possible sources of causing failures.

Based on the prior steps of analysis in stage REDP_B propositions that have been recorded till now for the design stage to be further checked, are:

- Substitute the use of mineral oils with natural or synthetic oils or use vacuum or materials in gaseous form as insulating or cooling means.
- Use high purity materials.
- Minimize the use of permanent and non-permanent junctions.
- Label each part with the materials it contains.
- Use parts with multiple possible uses.
- Maximize the number of parts that can be removed by using non-destructive methods.
- Availability of all necessary infrastructure and means for proper EOL treatment.
- Keep records of all tasks that have been taken place during service in product useful life.
- Availability of necessary means of protection.
- Take special measures for the danger of fluids to be released in the environment during the EOL treatment phase.

V. Conclusion

EOL treatment process in WEEE in real cases is usually predetermined based on the existing infrastructure and other necessary means. Even in cases where there exist more than one alternative the final choice is usually based on the cost and time minimization of the EOL phase. In this analysis the aim was to form an assisting tool for the decision maker to handle an EOL product of EEE based on its environmental consequences and afterwards to be able to improve the results of this procedure by proposing to the design phase possible actions to be examined for future application in product redesigning. The proposed method is an effort to form a general and simple frame of analysis able to be adjusted in any case of EEE product.

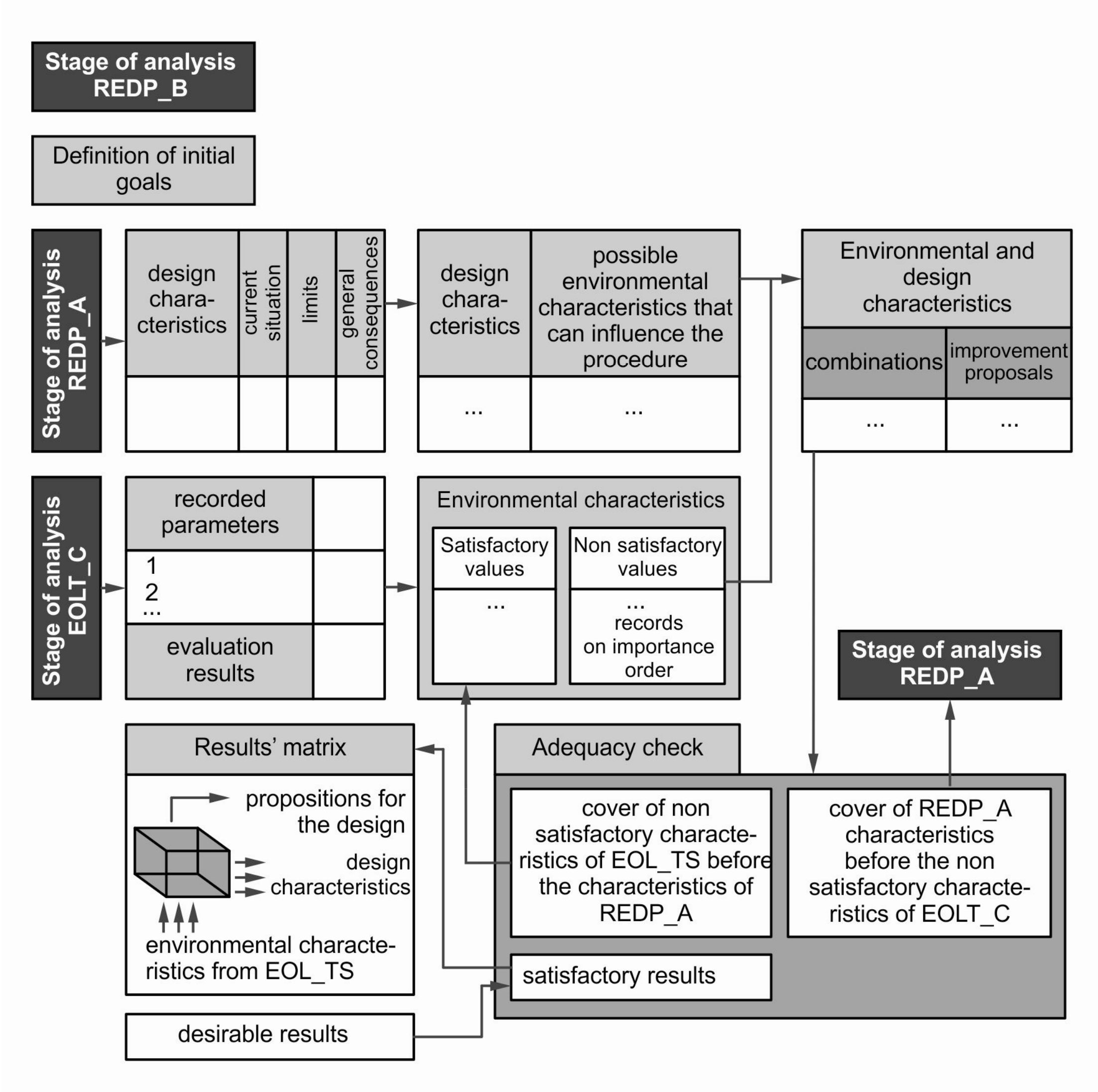

Fig. 5 REDP_B stage of analysis diagram

The results till today show that it is possible to get satisfactory results by using the proposed method. The intention for the future is to examine more categories of products of EEE in order to optimize the results of the analysis performed and based on product characteristics and external factors to propose possible tools of analysis to be applied for each stage of analysis.

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