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Evaluation of indicators supporting the sustainable design of electronic systems

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Abstract

Engineers are confronted with difficulties when it comes to the inclusion of sustainability aspects into the design process of electronic devices. Due to the specific nature and complexity of material composition, process flows and data availability there is a need for electronics-specific methodologies for environmental assessment. These need to allow for easy adaptation in all stages of the design process thus leading to a rapid identification of critical hotspots in system design. To fulfil this demand, indicators available for product-level assessment are evaluated with regard to environmental impact category coverage, practicability and significance for selected application fields of electronics. Case studies on sensor nodes and lighting products are used to show the application of indicator sets in industrial settings. As an outcome, indicator sets are identified that support the designer in keeping track of the overall sustainability of electronic products.

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Nomenclature

EPD Environmental product design
EPI Environmental performance indicator
LCA Life cycle assessment
LED Light emitting diode
PDP Product design process
PGM Platinum group metals
REM Rare earth metals
WSN Wireless sensor node

1. Introduction

The development of environmentally sound electronic products involves technology choices effecting all life cycle stages of the system. The design stage is considered the most relevant phase to reduce the environmental impacts of a product since it offers the largest degree of flexibility for modifications in functional layout, robustness and the related choice of components and interconnect technologies at minimum costs. It is assumed that 80 percent of the overall impacts are predetermined and set within the product design process (PDP) [1] from which point the possibilities to make major changes to improve the product decrease [2].

As a consequence, the design process must be supported by easily applicable and adaptable approaches for environmental impact assessment of the product with respect to selected life cycle stages. These approaches need to consider gaps and limited availability of system-related data especially in the very early and premature development stages of the design process. Uncertainty of the results based on the quality and predictability of the input data must be considered allowing for a step-wise adaption of the environmental impact assessment with increasing knowledge within the development process but also the products future life cycle.

The focus on electronic products is used to determine the evaluation criteria for existing approaches according to prevalent used components.

Emerged from the discrepancy of these assumption, the goal of this research is to set up a multi-level design method, consolidated of the existing assessment approaches able to link the primarily given input data to its environmental aspects. Based on predefined criteria in chapter 3.1 for evaluation,

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existing approaches are narrowed down to the most commonly used checklists, indicators, tools and life cycle based methodologies [3]. In the following section 1.1. the basics of the used approaches in chapter 3. are described, started from the low level assessment (checklist) to complex life-cycle-based methods.

1.1. Assessment approaches related to eco-design

Evolving technologies, miniaturisation and new complex materials and combinations make the materials choices for environmental friendly electronics increasingly difficult. Computer chips for example contained 12 materials in the 1980s, whereas in 2009 60 materials were used [4].

A prevalent first step within the PDP of companies is to develop white, grey and black material *checklists*. White lists typically categorise materials that should be used, grey lists contain materials that should be avoided if possible and black lists show forbidden materials [5]. The 2011/65/EU RoHS directive for example blacklists materials like cadmium, mercury or lead, based on human and environmental toxicity levels.

Though material checklists may be a practical approach at the design stage, for addressing the best eco-performance in an absolute sense it is useless considering how they might contribute to improve other life cycle impacts (e.g. lifetime extension, energy consumption etc..) [5].

Compressing more information, *indicators* are defined as condensed measures of a complex systems state that report changes and/or the state of a system in an easy and understandable way [6]. In the context of eco-design, environmental performance indicators (EPI) as defined in the ISO 14031 are used to measure the eco performance of products. EPIs are commonly used as effective factors for providing information on eco-design and environmental impacts. Key environmental performance indicators (KEPI) represent potential environmental impacts of particular relevance for a specific sector. KEPIs express the results of an environmental assessment by quantifying the environmental inventory and impact data relative to a reference e.g. a product or functional unit. Typical KEPIs are the cumulative energy demand (CED) and carbon footprint (CF) [7].

Life cycle assessment (LCA) methodologies detail a variety of measures and indicators in order to measure the eco-performance of a product by assessing environmental impacts over the entire life cycle. According to the ISO 14040 standards, the assessment of the product with a LCA gives impact information about the product to improve its eco-performance, to set sustainable goals or to achieve an Environmental Product Design (EPD) certification. Although the usage of LCA methodologies may be comprehensive, their use during the design stage can soon become inefficient. Known barriers within the PDP are the complexity, data availability, transparency, unclear system boundaries and weighting leading to a time consuming analysis [3] [8]. Furthermore it is difficult for designers to relate to the results, since they are classified in impact categories like ozone depletion or photochemical oxidation.

Conclusively, the variety of those existing approaches differs in various aspects like the required input data or significance of the category, enlarging the complexity and leading to difficult choices for designer on appropriate approaches. For this reason it is necessary to evaluate the existing assessment approaches according to their practicability in analysing electronics.

2. Criteria for evaluating assessment approaches

For the existing approaches, in particular indicators, evaluation criteria was set up with regard to the mentioned discrepancy: approaches have to fulfil the trade-off between the limitations drawn by the design stage and the quality and range of the resulting measures and indicators.

As a commonly used approach for setting up evaluation criteria, the "RACER criteria" as outlined below was adapted to meet the mentioned problems and objectives of the electronics designer at design stage. In addition to the set up criteria, approaches that do not apply to the product level or to electronic products were neglected.

Robust: reproducible data; comparable and applicable to further or new generations

Accepted: accepted by electronic designers by means of applicability on product level; applicability to electronic systems;

Credible: easy to evaluate and interpret;

Easy: minimum input data required; data availability at design stage; low calculation time;

Relevant: quantitative data; based on chemical and physical characteristics; linked to environmental impacts;

3. Consolidated method for sustainable electronic design

With the specified RACER criteria, several assessment approaches were evaluated. In this process e.g. qualitative indicators have been neglected, since they don't follow the set up criteria (high information input & calculation efforts). As a result of this research, two main approaches were adapted within the evaluation. First a checklist for specific critical electronic materials were developed to reduce the materials to examine. Secondly, to enable a comprehensive assessment, the evaluated indicators were embedded into a life cycle based matrix, with regard to their impact category. In total, the method consolidates four steps:

1. Obtain raw data from three proposed data sources
2. Setup a checklist for specific electronic materials
3. Chose indicators from indicator matrix that links the energy, material and emission impacts to three life cycle stages
4. Optional: build use case scenarios and conduct a hotspots analysis