Modeling and Analysis of Sustainability in Product Life Cycles

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Abstract. This paper describes a work-in-progress, design-oriented approach to support the analysis of sustainability in product life cycles. The envisioned system provides a modeling method for structuring and collecting information about a product life cycle. By adapting analysis methods from the research field of environmental and social life cycle assessment, it further allows to explore and identify sustainability risks.

Keywords: Domain-Specific Modeling Languages, Enterprise Modeling, Sustainability, Life Cycle Assessment

1 Introduction

The recently adopted United Nations resolution "Transforming our world: the 2030 Agenda for Sustainable Development" [12] is an example of the growing global awareness for environmental, economic and social problems. The complexity of these problems calls for a collaborative effort of all societal actors, be it governments, firms, NGOs, or citizens, in finding and implementing solutions. One of the goals formulated in the resolution is sustainable consumption and production. This highlights the responsibility of consumers and producers in the context of sustainability. However, consumers and producers alike face an information gap: the question 'how sustainable is a product?' is not easily answered. But gaining the relevant information will enable them to make informed decisions regarding a product's sustainability characteristics. The work presented in this paper aims to solve this problem from modeling perspective, whereby the two guiding research questions are:

- How to assess a product's sustainability?
- How to visualize and communicate a product's sustainability?

This paper proposes a design-oriented approach [9] that contributes to the field of enterprise modeling, by developing a modeling method [7] for product sustainability. The modeling method is part of an information system that enables researchers and practitioners to model and analyse product life cycles with respect to sustainability.

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The following section 2 describes this general vision and research idea in more detail: the envisioned artifacts and the background is laid out. As a first step towards this goal, the author has developed a domain-specific modeling language (DSML) and software tool that is limited in scope, but already supports assessment and visualization of certain aspects of product sustainability. This initial step towards the research goal is described in section 3. Section 4 draws a conclusion and briefly discusses future work.

2 A Design-Oriented Approach to Product Sustainability

Design-oriented IS research, as proposed by Österle et al. [9], means to develop and evaluate artifacts that provide utility to specific stakeholders by solving a specific problem. In this case, the focused stakeholder group consists of organizations, e.g. firms and NGOs, who want to analyze a product's sustainability. Organizations willing to disclose the gained knowledge shall further be supported in providing transparency to external stakeholders, like customers or suppliers.

As the most common definition of sustainability - to meet the needs of the present without compromising the ability of future generations to meet their own [11] - takes a global perspective, a product in itself can never be sustainable in this global sense. However, its production and use can have various levels of effects on global sustainability (see [6]). Taking as example a modern ICT product like a smartphone or a laptop, potential sustainability problems can be identified along the whole life cycle: from the mining of so called "conflict minerals" that finance armed conflicts in Central Africa [2] to the illegal shipping of electronic waste to developing countries, where the products are disassembled under hazardous conditions [1]. Regarding the domain of product sustainability, the life cycle assessment (LCA) research community provides methods for identifying and assessing these effects. But due to the complexity of LCA studies' results, the presentation of a LCA study is not an easy task. Within the LCA community, general tool support and models for presentation of findings are thus seen as an important research gap [10].

Therefore, the main research idea is to design a modeling method for product sustainability that incorporates a LCA perspective. A modeling method consists of a modeling language, a modeling procedure, and supporting mechanisms and algorithms [7]. These elements can then be implemented in an information system that supports the assessment of product sustainability to allow for informed decisions. The user roles of modeler and viewer have differing needs concerning such a system. A viewer might only be interested in aggregated visualizations and results based on the created models. But, in order to improve the quality of the results, the models need to be as detailed as possible. This motivates the need for specific mechanisms and algorithms that perform calculations on the input models and transform detailed models into aggregated visualizations. The envisioned modeling language and procedure, as well as the necessary mechanisms and algorithms are described in the following:

Modeling Language and Procedure: A meta-model of product sustainability forms the conceptual basis. It further describes and structures the problem domain. The general idea is then, to develop a DSML based on the meta model. The language will be implemented in a software tool that serves several purposes: (1) To support a prospective modeler in structuring and collecting information about a product life cycle. (2) To enable a viewer to explore and identify sustainability risks within the product life cycle. Furthermore, the tool may introduce means for collaboration among users e.g. to complement supply chain data. The integration of generic sustainability data (e.g. data on working conditions in different countries and sectors as published by international organizations like ILO) then complements the user generated data.

Mechanisms and Algorithms: In order to provide aggregated results and perform assessments, the proposed system draws inspiration from LCA methods. Examples for computational analysis methods that were developed for (environmental) LCA make use of sequential methods, linear programming or petri nets [5]. Any of them may potentially be adapted for the proposed system. However, as the goal is to integrate environmental and social assessment, the methods need to be evaluated regarding their adaptability to a joint application.

3 Initial Steps and Existing Work

As a first step towards the research goal outlined above, the author has developed a DSML named 'TracyML'. The modeling language serves the purpose of visualizing social risks within a product life cycle. In its current state, TracyML focuses on the early life cycle phases from extraction of raw material to the assembly of the final product. It is further restricted to the stakeholder group workers and visualizes social aspects like the risk of forced labour or excessive working hours. The language was developed by adapting guidelines for the conception of DSMLs proposed by Frank [4]. It features a meta-model and a graphical notation, which was developed with an emphasis of usability and understandability.

Additionally, a web-based prototype modeling tool was developed. A running instance and the source code is available under www.gotracy.org. It implements the features of TracyML, and further visualizations based on user-created models. As part of the evaluation, the software tool was applied to two ICT product use cases, a computer mouse (www.nager-it.de) and solder wire (www.fairloetet.de). In both cases, the organizations provided supply chain data that could be used to model the extraction of raw materials and assembly of components.

4 Conclusion and Outlook

The next step is to extend the TracyML meta model to a broader sustainability perspective, covering social and environmental aspects. The preceding work has laid the basis for the envisioned information system, but already exposed some challenges. For example, in order to not overload the user, on the one hand

the complexity of a modeling language should be kept in check [8]. But on the other hand, as system visibility is an important enabler for sustainability [3], the underlying assumptions and calculations should be traceable for the interested user. Here, the developed solution needs to strike a balance between simplicity and traceability, which needs to be continuously evaluated. To summarize, the work presented here contributes to enterprise modeling by addressing the arising challenge of product sustainability. The results provide utility for firms, NGOs, and consumers. Prospective users are supported in identifying sustainability issues in a product life cycle, and deducting courses of action through informed decision.

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