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Analysing the Cumulative Energy Demand of Product-Service Systems for wind turbines

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Abstract

Many wind turbine manufacturers offer services for their products. The integration of products and services, so called Product-Service Systems (PSS), are intended to support customers over the life time of a product and to ensure a long and successful customer relationship. Besides of the requirements of customers, wind turbine manufacturers have to consider requirements of the government and society as well. Sustainability in all three dimensions, economy, environment, and society, is increasingly relevant in engineering. PSS providers have the possibility to improve sustainability of their products and services over the entire life time and supply chain. For this purpose, novel methods need to be provided to support PSS providers to evaluate and improve PSS sustainability.
In this paper, an approach to analyse and reduce the Cumulative Energy Demand (CED) of PSS is presented to improve economic and environmental sustainability. The approach is explained on a wind turbine including training as service. In the approach three subgoals are addressed: First, CED of PSS is investigated. Second, the impacts of changes in the CED of PSS will be analysed, potential levers will be identified and measures derived. Third, strategies based on the measures will be generated which enable a reduction of the CED of PSS.

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Keywords: Product-Service Systems; Cumulative Energy Demand; sustainability; wind turbines

1. Introduction

Changed requirements of customers caused a trend from technology providers to service providers. Customers are interested in complete and sustainable solutions. Product-Service Systems (PSS) aim to achieve sustainability and customer satisfaction by systematically providing various services for products [1]. PSS offer life cycle-oriented services to support customers over the entire life time of their product. PSS are strongly customer-oriented and it is assumed that PSS provide the ability to reduce environmental impacts. However, it is not guaranteed [2] and not proven on any use cases. For an evaluation of environmental impacts of PSS, an ecological assessment is needed. The Cumulative Energy Demand (CED) is an opportunity to assess and evaluate the sustainability of a single product or a service based on energy. It describes the "total quantity of primary energy which is necessary to produce, use and dispose a product" [3]. The CED in its existing state is not suitable to evaluate a complex system consisting of products and services as it is the case for PSS. It needs to be adapted and enhanced due to the PSS-specific characteristics. Therefore, the paper demonstrates an approach to analyse and reduce the CED of PSS. The first part starts with the state-of-the-art about CED, followed by the state-of-art of PSS and the relevance of services for wind turbines. Based on the existing research work, the need for a PSS-specific approach for determining the CED is explained. The main part of the paper is dedicated to the approach which is developed in a research project. It presents how to enlarge the current CED method so that it is adaptable for PSS in respect of wind turbines. Finally, the paper ends with a conclusion and further research work on the approach.

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2. State-of-the-art

2.1. Cumulative Energy Demand

Cumulative Energy Demand is a part of the Life Cycle Assessment (LCA). CED enables to evaluate and compare products and services with respect to energy criteria. Hereto, the primary energy demand, all energy carriers that are found in nature, will be calculated for the entire life time of the investigated product. CED is the sum of the cumulative energy demands for the production (CED_P), for the use (CED_U) and for the disposal (CED_D) of the economic good. [3]

$$CED = CED_P + CED_U + CED_D \quad (1)$$

The VDI guideline 4600 suggests a method for determining CED of products and services [VDI4600]. For the calculation of CED the sum of cumulative energy consumption (KEV) and the cumulative non-energy demand (KNA) are necessary. The KEV includes all the final energies for heat, energy, light and other forms of effective electricity generation which are valued as primary energy. The KNA defines the sum of all non-energy purposes and the inherent energy of working materials which are also valued as primary energy. [3]

An important basis for the calculation of the CED is the definition of the balancing boundaries and the balance-sheet items. For this purpose, the material and energy flows have to be defined and quantified. The boundaries can be defined according to local, temporal and technological criteria. A determination of all pre and incidental process chains is not possible and the systematic limitation is a challenge because of the complexity and multiplicity of the interactions of individual processes. Therefore, the delimitation between relevant and not relevant process chains is important. To this, delimiting criteria exist. In an ideal case the balance space is from the raw material of the deposit to the final disposal. A redefinition of the criteria for the boundary setting has to be done because the balance boundaries are defined based on facts and circumstances at the beginning of an analysis and might change over time. Furthermore, a sensitivity analysis with varying balance boundaries is necessary during the calculation of the CED to assess the impacts of different balance boundaries. [3]

Methods for balancing are the process chain analysis used in form of a material balance analysis, a micro- and macro-analysis as well as an energy input-output analysis.

The process chain analysis is a micro-analysis where the product flow is classified into individual processes according to the production process. Originating from the final product each step from the production to the disposal is analysed which is necessary for the process chain. The first step starts with an analysis of the production of the assemblies. In the next, more detailed step the production of the semi-finished products and raw materials are considered. For this method, the amount of data is high and it may reach its limits of practicability. For the determination of CED a step-wise approximation, using a combination of micro-analytical and macro-analytical approaches, is recommended. [3]

The macro-analysis is based on values of input and output flows of products of homogeneous production areas. The energy input-output analysis is based on national data on economic interdependence and energy use. It is not suitable for the determination of the CED of individual products because of the degree of aggregation and reference to monetary values. [3]

For the determination of the CED of PSS the typical characteristics of PSS need to be known, analysed and adapted into the new approach. The next section presents the most important characteristics of PSS.

2.2. Product-Service Systems

Product-Service Systems are defined as consumer-oriented solutions consisting of a technical product which is supported and enhanced over its entire life time with different services [4]. Services can be classified according to the life cycle phases or by their functionality into six types [4]: technical, qualifying, process-oriented, logistical, informational and financial. Technical services like maintenance are focused on recovering the functions of a product. Qualifying services improve the quality of work of customer employees, e.g. operator training. Process-oriented services optimise the production process of the customer and logistical ones support spare part supply. Informational services are reports and the supply of information for the customer. Financial services help customers by providing leasings.

PSS have a customer-oriented perspective instead of product-oriented. They have a comprehensive life cycle compared to a single product as they contain life cycle perspective of the manufacturer as well as of the customer (see figure 1). The manufacturer and customer have a cooperation during the usage of the product. Both act as external and internal production factors during the whole work process [4].

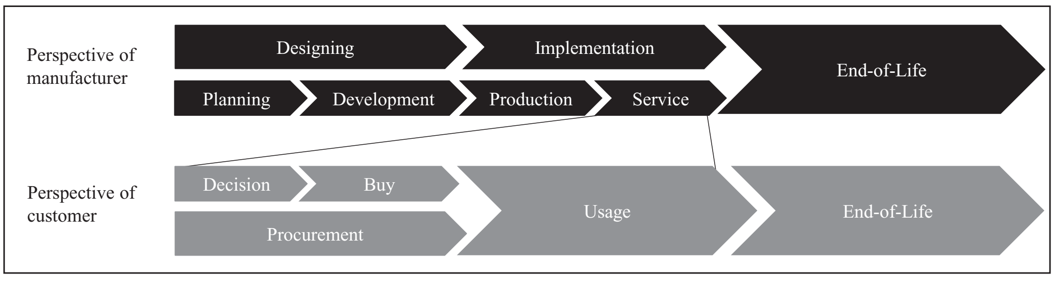

Figure 1: PSS life cycle from the perspective of manufacturer and customer [4]