A Web Based Application for the Eco-PaS Tool

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Abstract

The Eco-PaS methodology supports anticipative weak point analysis of a product's life cycle environmental impact. Using quantitative information available in early design stages, the order of magnitude of an environmental indicator is estimated. This result is obviously influenced by a number of uncertain factors. However, a critical analysis of these factors allows pointing the designer at promising design directions at a time in the design process when many degrees of freedom remain open. This paper recapitulates the principles of the Eco-PaS methodology, and introduces a web-based application of the Eco-PaS tool.

Keywords

Eco-PaS, environmental impact screening, conceptual design, web-based tool

1 INTRODUCTION

The assessment of a product's environmental profile is typically performed using Life Cycle Assessment (LCA). However, a full LCA requires the identification and quantification of the emissions, energy and material flows throughout the lifecycle of a product. Often several hundreds of processes need to be scrutinised, making LCA a very time-consuming assessment technique. In a product development context, data availability is even more problematic, since many decisions yet need to be taken. Therefore, LCA is only suited for ex-post assessment of the design process result.

In order to achieve the significant data need (and cost) reductions required for ex-ante assessment, rough environmental assessment methods have been developed that are now used by a number of frontrunner companies ([1], [2]). They eliminate the extensive data gathering efforts connected to tracing all life cycle processes and their related elementary flows (emissions, waste, material and energy) by making use of average data for common sections of a product life cycle. Based on these average data, an impact assessment is performed using a standard LCA methodology (e.g. Eco-indicator'99 [3]), thus leading to e.g. indicator scores per kg of material or per kWh of electricity. Standard values are typically available for materials (per kg material), production processes (e.g. per square metre of rolled sheet or per kg of extruded plastic), transport processes (per tonne-kilometre), energy generation processes (per kWh or MJ), and disposal scenarios (per kg of material).

In order to use these rough environmental impact calculation methods, the materials inventory and a list of product life cycle processes is required. The need for a detailed materials inventory however limits the applicability of the simplified LCA methods in the design process. For example, during early design phases, when only functional requirements and product concepts are available, the materials inventory is yet undefined. Nevertheless, decisions taken in the conceptual design phase can influence the outcome of a design exercise far more significantly than any optimisation step later on in the design process [4]. In an eco-design approach an early recognition of favourable system component solutions is therefore of great importance. Moreover, even for fully developed products, a detailed materials inventory is difficult to obtain when many components are bought off-the-shelf. This especially holds true for small and medium-sized enterprises, which can provide little incentives to enforce suppliers to provide the requested data.

2 THE ECO-PAS METHODOLOGY

2.1 Eco-Cost Estimating Relationships (E-CERs)

As a solution to the highlighted problems, we have introduced the Eco-PaS methodology (Eco-Efficiency Parametric Screening) [5, 6, 7]. Eco-PaS makes use of Eco-cost estimating relationships (E-CERs), defined as mathematical expressions relating an eco-cost as dependent variable to one or more independent eco-cost driving variables. In this framework an eco-cost can be expressed in monetary units, such as external costs or willingness to pay, or by any other commonly used environmental performance indicator, such as, for example, the Eco-Indicator99 [3] that will be used in this paper. The eco-cost driving variables are functional requirements (FR) or design parameters (DP) that product developers have at hand when designing or selecting components from catalogues. Consequently, parametric expressions are used which express the environmental impact ξ as a function $\xi = f(FR, DP)$. For example, the cradle-to-gate Eco-Indicator'99 score ξ for the production of electric motors can be estimated based on their nominal power P_{nom}: $\xi = f(P_{nom})$.

The E-CERs can be derived using theoretical model development, regression analysis on empirical data and growth laws [8]. As an example, we derive the E-CER for a recipient. From a functional point of view, the major functional parameter is the amount V[m³] of gas, liquid or bulk material the recipient can contain.

First consider a hollow cubical recipient with open top side and lenth b[m], hence

$$V = b^3 \qquad (1)$$

Assuming a wall thickness t[m] and negligible production waste, one easily calculates the amount of material A[m³] needed to produce the recipient:

$$A = 5\, b^2\, t = 5\, V^{0.66}\, t = \alpha_i\, V^{0.66}\, t \qquad (2)$$

The coëfficiënt 5 in this equation is typical for open cubical volumes; Table 1 presents the shape factor α_i for other recipient geometries.

For a material with environmental impact score ξ_j [Points/m³], Equation 2 can be rewritten as

$$\text{Impact score} = \alpha_i\, \xi_j\, V^{0.66}\, t \qquad (3)$$

Table 2 shows the material factor ξ_j for a selection of materials.

Shape	*Remarks*	*Shape parameter α_i*
Cube	One side open	5.0
Half sphere	One side open	3.8
Cylinder (one side open)	Diameter = height*2	4.4
	Diameter = height	4.6
	Diameter = height /2	5.2
Cone (one side open)	Diameter = height *2	6.4
	Diameter = height	4.6
	Diameter = height /2	4.0

Table 1 -Value of the shape parameter α_i for various recipient shapes

Material	*Material parameter ξ_j*
ABS	428 Pt/m^3
PC	600 Pt/m^3
PP	300 Pt/m^3
PS	420 Pt/m^3

Table 2 - Value of the material parameter ξ_j for recipients

2.2 Uncertainties

While it is well-known that the calculation of a product life cycle's environmental performance is subject to a number of uncertain factors, it is obvious that the estimation of environmental impact using E-CERs is subject to an even higher degree of uncertainty.

In early design phases, the designer using the E-CER of Equation 3 has not selected the material yet, nor the final shape. The wall thickness is probably one of the last design steps, and even the functional requirement on how much liquid the recipient should be able to contain can still be an uncertain element depending on the detailed design of other components.

Therefore, both the user input as well as the E-CER coefficients can be defined as possibility ranges or fuzzy sets. An example of how environmental impact scores and ranges can be used to steer a design process is given in Section 3. An elaborate description of the uncertainty elements in Eco-PaS is available from [9].

2.3 The Eco-PaS Webtool

In order to allow an easy access to the Eco-PaS methodology, a web based prototype has been developed. The prototype is based on a system architecture in three layers: information, application and presentation (Figure 1).

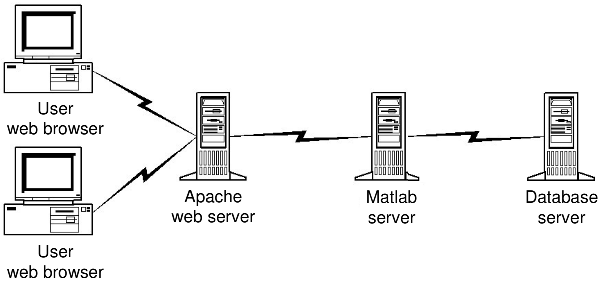


Figure 1 – System architecture of the Eco-PaS prototype implementation.

The information platform consists of a relational database (MS Access) to ensure structured data storage. The application layer covers the Eco-PaS functionality needed to manipulate data, such as handling product definition data and user input or calculating environmental impact scores and related uncertainties. The implementation of the application layer is based on MATLAB functionality, which communicates with the MS Access database using SQL queries. Finally, the presentation layer is using simple HTML code.

3 DEFINITION AND ANALYSIS OF PRODUCTS AND COMPONENTS WITHIN THE ECO-PAS WEBTOOL

This section zooms in on the definition and analysis of respectively a single component (Section 3.1) and a full product (Section 3.2) using Eco-PaS. In both cases, the analysis is presented from a user's perspective.

3.1 Definition and analysis of a single component

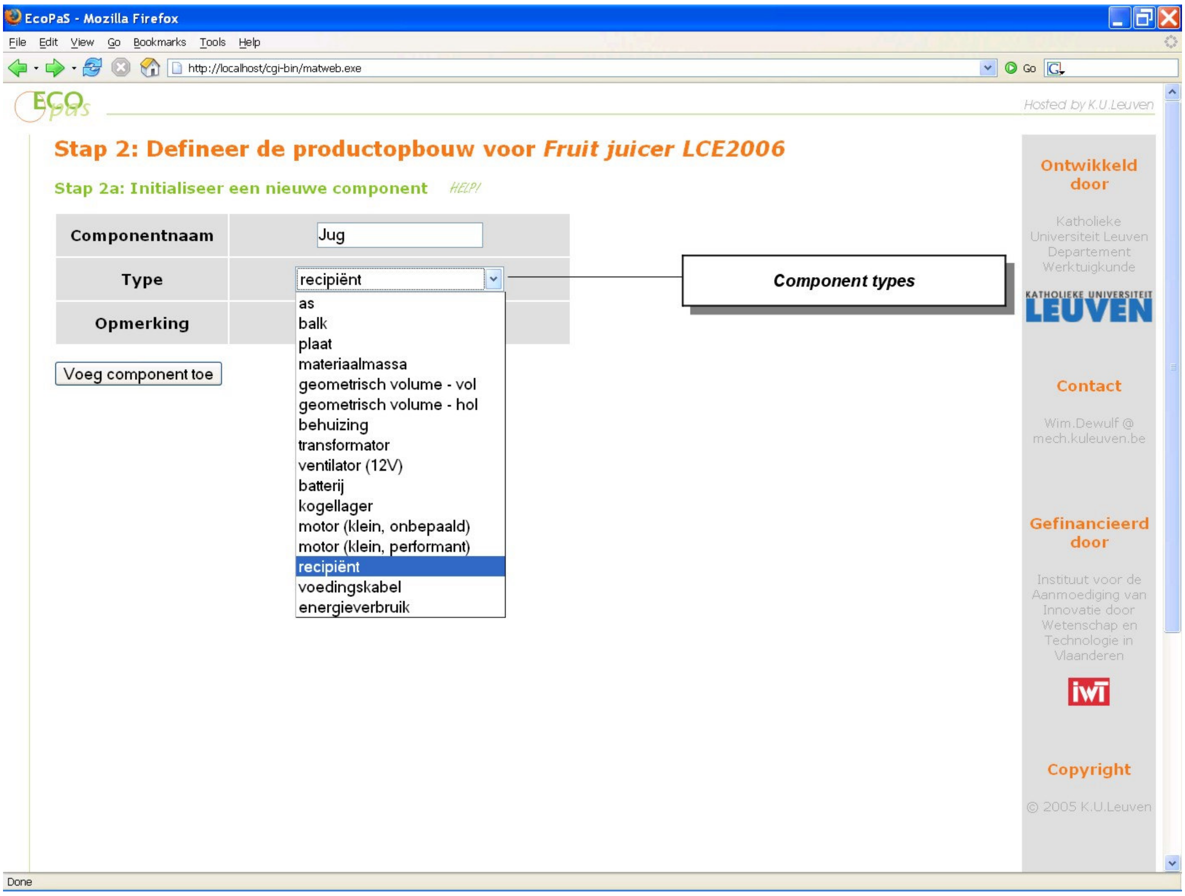
Definition and analysis of a single product module within the Eco-PaS webtool starts with its characterisation as one of the predefined module types (Figure 2). Available types range from electric components (motors, transformers, electric wires, batteries) to structural and mechanical components (bearings, beams, housings, recipients, shafts). The further extension of the available type list is crucial for the practical usability of the tool, and requires a continuous research effort.

The definition of the module further requires a quantification of a number of functional parameters, dependent on the selected module type. The 'jug' initialised in Figure 2 as 'recipient' requires primarily the quantification of the recipient's volume. Since the exact magnitude of the recipient might still be uncertain during the early design phase, both an estimate and a possibility range can be inserted (Figure 3).

For the recipient, two more properties of the jug can be given, i.e. the material (type) and the shape, although a specification of these properties is not mandatory. Hence, in the given example, the shape is left as 'unknown' while the material has been defined as 'plastic'. The Eco-PaS tool immediately translates this information into a quantitative range of respectively [3.8 6.4] and [300Pt/m^3 600Pt/m^3] for parameters α_i and ξ_j respectively (See Tables 1 and 2). Note that the wall thickness t of Equation 3 is not required as an input parameter. Since it is considered to detailed a parameter for early design phases, it is modelled default as ranging from 0.5 to 2mm.

Based on the functional parameter information given by the designer, the tool calculates both an estimate for the environmental impact score as well as a possibility range (Figure 4). It is obvious that the vagueness of the input parameters (material 'plastic', shape 'unknown',…) results in a rather large possibility range. Nevertheless, as will be shown in Section 3.2, this order of magnitude calculation already allows comparing the potential impact of 'jug' with other product subsystems, hence identifying environmental hot spots of the assessed design.

Moreover, the Eco-PaS tool calculates the influence of the uncertainty of the individual input parameters on the overall component result. In the example of Figure 4, the Eco-PaS tool shows the user that the determination of the exact jug volume is of minor importance, in comparison with the dominance of the material selection problem. Note the presence of the model uncertainty as one of the constituting elements of the overall possibility range. It represents the uncertainty on the result that remains even if the user input consists of only crisp values. It often originates from a distribution of data points around an E-CER calculated using regression analysis. In this example, the model uncertainty originates from the default modelling of the wall thickness t as [0.5mm 2mm].



Stap 2: Definieer de productopbouw voor *Fruit juicer LCE2006*

Stap 2a: Initialiseer een nieuwe component HELP!

Componentnaam	Jug
Type	recipiënt
Opmerking	

as
balk
plaat
materiaalmassa
geometrisch volume - vol
geometrisch volume - hol
behuizing
transformator
ventilator (12V)
batterij
kogellager
motor (klein, onbepaald)
motor (klein, performant)
recipiënt
voedingskabel
energieverbruik

Component types

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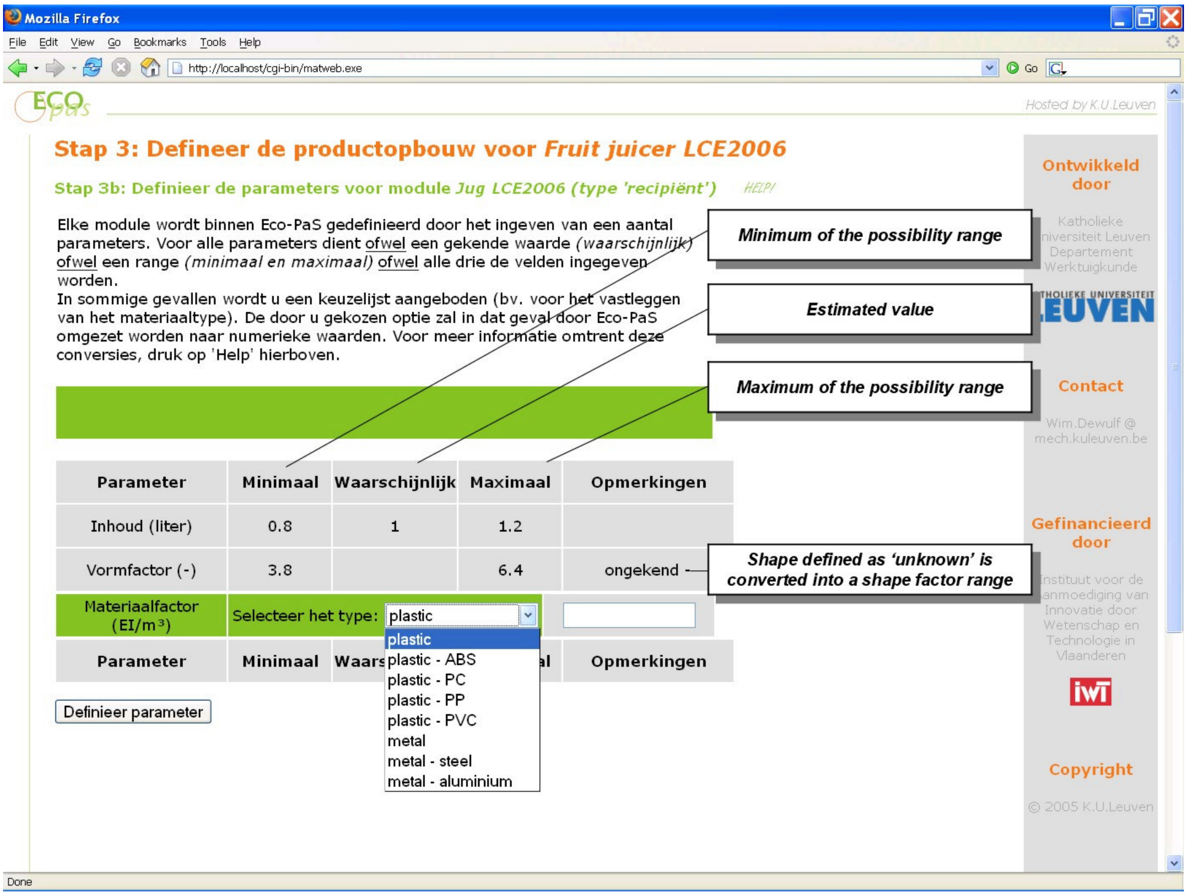
Figure 2 – Characterisation of a component using a predefined typology



Stap 3: Definieer de productopbouw voor *Fruit juicer LCE2006*

Stap 3b: Definieer de parameters voor module *Jug LCE2006 (type 'recipiënt')* HELP!

Elke module wordt binnen Eco-PaS gedefinieerd door het ingeven van een aantal parameters. Voor alle parameters dient ofwel een gekende waarde *(waarschijnlijk)* ofwel een range *(minimaal en maximaal)* ofwel alle drie de velden ingegeven worden.
In sommige gevallen wordt u een keuzelijst aangeboden (bv. voor het vastleggen van het materiaaltype). De door u gekozen optie zal in dat geval door Eco-PaS omgezet worden naar numerieke waarden. Voor meer informatie omtrent deze conversies, druk op 'Help' hierboven.

Parameter	Minimaal	Waarschijnlijk	Maximaal	Opmerkingen
Inhoud (liter)	0.8	1	1.2	
Vormfactor (-)	3.8		6.4	ongekend
Materiaalfactor (EI/m³)	Selecteer het type: plastic			
Parameter	Minimaal	Waars	l	Opmerkingen

plastic
plastic - ABS
plastic - PC
plastic - PP
plastic - PVC
metal
metal - steel
metal - aluminium

Minimum of the possibility range

Estimated value

Maximum of the possibility range

Shape defined as 'unknown' is converted into a shape factor range

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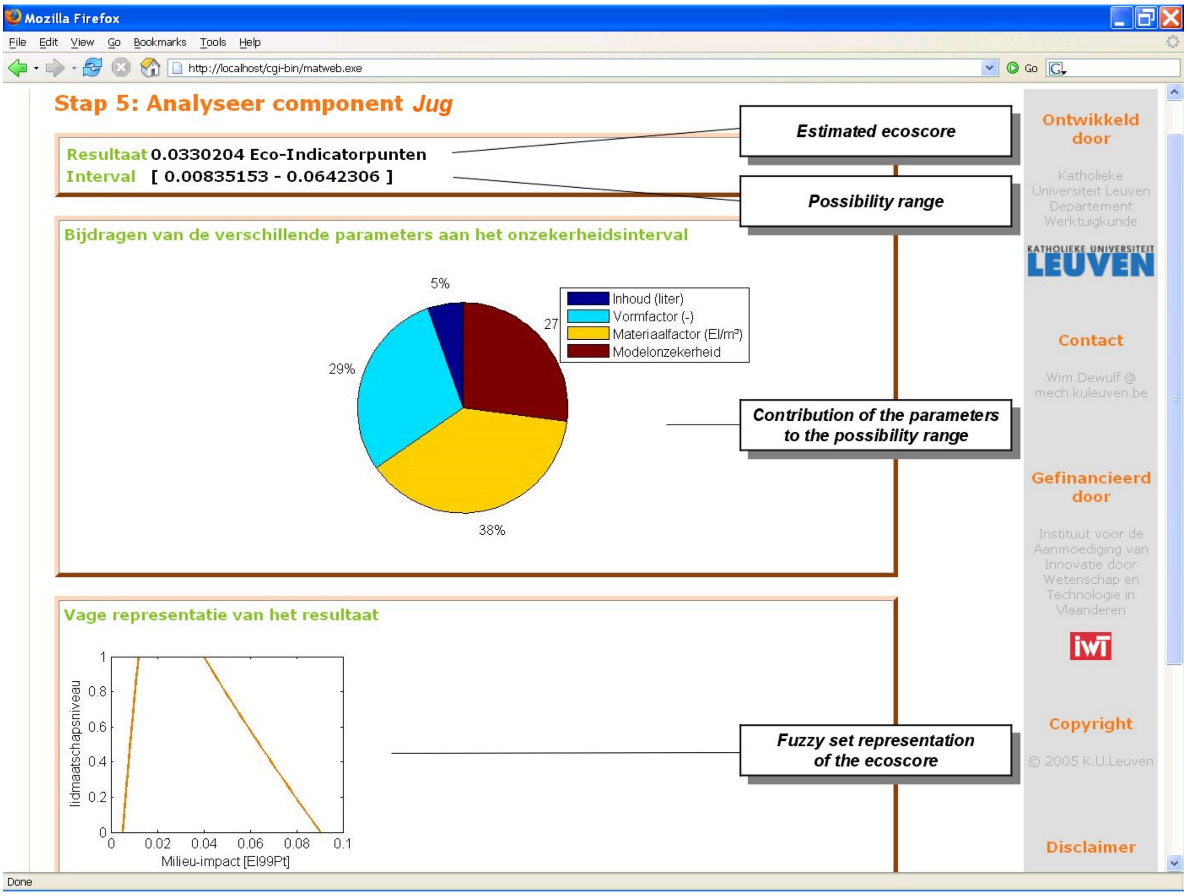
Figure 3 – Component definition



Stap 5: Analyseer component *Jug*

Resultaat 0.0330204 Eco-Indicatorpunten
Interval [0.00835153 - 0.0642306]

Bijdragen van de verschillende parameters aan het onzekerheidsinterval

Vage representatie van het resultaat

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Figure 4 – Assessment of a single component

3.2 Definition and analysis of a product

A product is defined as a combination of multiple components, each defined according to the procedure explained in Section 3.1. A complete analysis of the product by Eco-PaS results in four types of information. First, an overall environmental impact score estimation is given. Evidently, this estimation is very uncertain, hence an overall possibility range for the calculated score is given as a second indication.

Third, the contribution of each constituting component to the overall environmental impact score estimation is presented. Finally, Eco-PaS calculates the contribution of the constituting components to the possibility range of the overall environmental impact score (Figure 5).

Both the contribution of a component to the overall environmental impact and its contribution to the overall possibility range are important. A large share in the overall score indicates an environmental hot spot in the environmental profile of the product. If its share in the overall possibility range is also substantial, an environmentally conscious detailing of the considered component is a clear eco-design opportunity. If, however, its contribution to the overall possibility range is small, the overall product is likely to have little or no substantial improvement potential.

4 SUMMARY

This paper presented a web-based prototype for the Eco-PaS methodology. Next to a short recapitulation of the methodology fundamentals, the system architecture was described. Finally, a number of interfaces were shown illustrating the use of the prototype.

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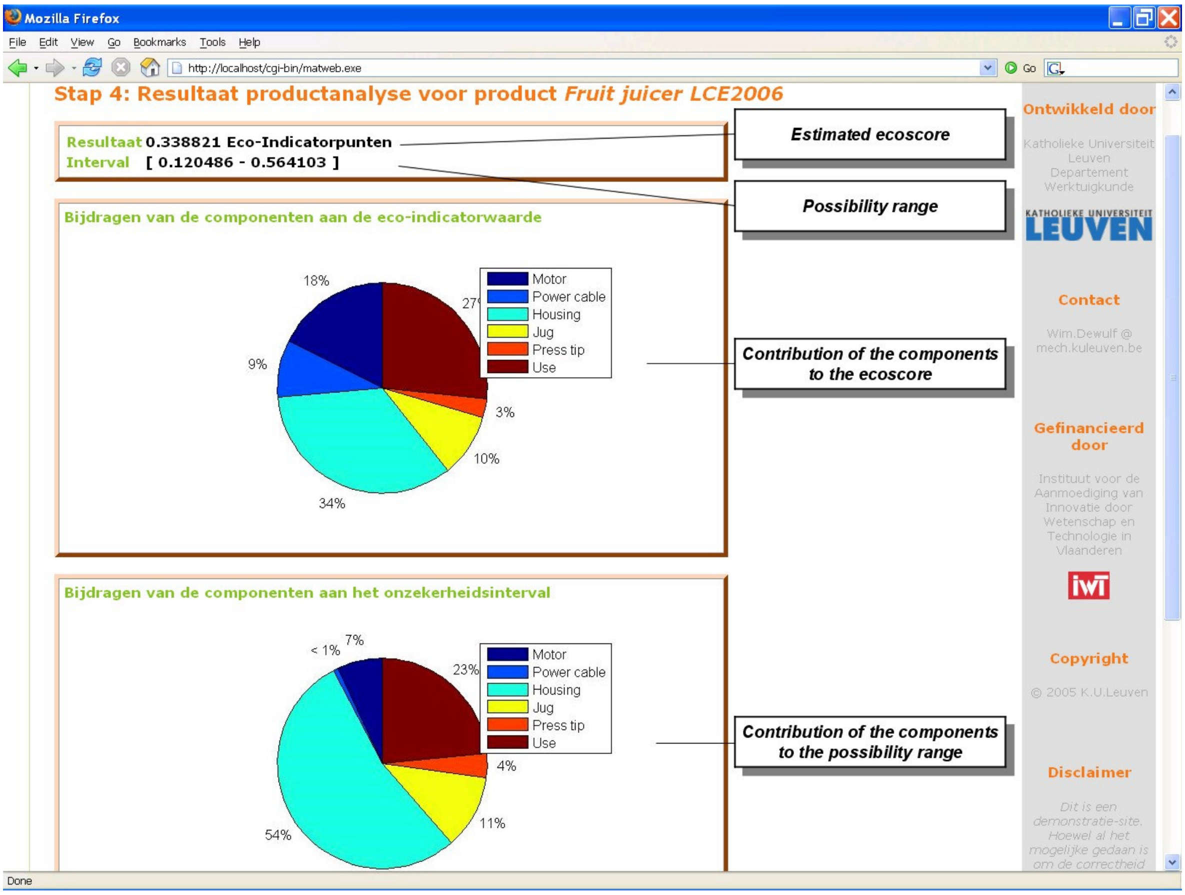

Stap 4: Resultaat productanalyse voor product *Fruit juicer LCE2006*

Resultaat **0.338821 Eco-Indicatorpunten**
Interval **[0.120486 - 0.564103]**

Estimated ecoscore

Possibility range

Bijdragen van de componenten aan de eco-indicatorwaarde

Contribution of the components to the ecoscore

Bijdragen van de componenten aan het onzekerheidsinterval

Contribution of the components to the possibility range

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Figure 5 – Assessment of a product consisting of multiple components