SYSTEMATIC FRAMEWORK FOR THE DEVELOPMENT OF FUONS

Ostad-Ahmad-Ghorabi, Hesamedin; Collado-Ruiz, Daniel

Abstract

Life Cycle Assessment is one of the most popular environmental assessment tools. However, due to its comparative nature, assessing a newly developed product relies on having benchmark information. Since data on previous products is bound not to be of identical products, this entails scaling on functional terms (i.e., in terms of the product's functional unit). For that reason, the authors developed the concept of LCP-families for scaling, and that of fuons to standardize the parameters by which they would be scaled. In order to facilitate the development of new fuons, a systematic stepwise approach is presented in this paper. Step one defined the basic functional flows of the fuon, step two defines and analyzes the scaling parameters through a linear regression model, and step three covers parameters that can potentially differentiate between LCP-families. The framework is shown in the development of two fuons in a case study, and their statistical suitability to be used in scaling through LCP-families is assessed.

Keywords: LCP-families, Ecodesign, Life cycle assessment, Product development, Functional unit

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1 INTRODUCTION

The turn of the millennium has seen sustainability turn into a key strategic point in society. Not only manufacturing processes must be cleaner. Be it called ecodesign, design for environment or design for sustainability (Waage 2007, Howarth and Hadfield 2006, Karlsson and Luttropp 2006, McAloone 2003, Coulter et al 1995), products have to reduce their overall footprint on the environment. In order to tackle the relevant problems, environmental information is generally presumed to be necessary. Life Cycle Assessment (LCA) is one of the most widespread methods for this (Jeswiet and Hauschild 2005, Germani et al 2004, Ernzer et al 2001, among others), and even those approaches that avoid a complete LCA include its principles in some way (Ernzer and Birkhofer 2003, Erzner and Wimmer 2002, Brezet and Van Hemel 1997).

However, LCA finds detractors because of a series of reasons (Millet et al 2007, Sousa and Wallace 2006, Ernzer and Birkhofer 2003, Jönbrink et al 2000): it is time consuming, complex, and results have an intrinsic uncertainty. Furthermore, since LCA is of a comparative nature (ISO 2006), results can only be relevant for design in relative terms, by comparing different life cycle phases, parts, processes or similar products (Lenzen and Treloar 2003, Heijungs, R. and Suh, S. 2002, Wenzel et al 1997) to a benchmark. In the latter, should additional functionalities have been added to a new product extrapolation from previous yet different products is necessary.

In order to ease this challenging situation, Collado-Ruiz and Ostad-Ahmad-Ghorabi (2010a) introduced a methodology to come up with references ranges. Reference ranges are those in which products can be assessed as to their better or worse environmental performance in comparison to competing products, independently to their technology. To group products to serve as a reference for those ranges, product families for LCA comparison (or LCA Comparison Product Families, in short LCP-families) were developed. Target environmental impacts can be defined already in early product development stages (Kobayashi et al 2005, Hoffman 1997). Those targets can be compared with the actual environmental impact values in the later stages when LCA data is available (Lindahl 2005). Through reference ranges it is possible to judge whether the new product is doing better, same or worse than its reference from an environmental point of view.

However, product comparison is only possible in case products have the same Functional Unit (FU) (ISO 2006). The FU has the role of evening the contribution of different products in LCA and making them comparable. Products that share common traits in their FUs are candidates to be grouped into the same LCP-family. This can become difficult with new products and added functionality. If their functional performance is different, their LCA results should be scaled according to the magnitude of the reference flows (ISO 2006). This requires a structured and uniform definition of the FU.

To ensure that the FU is set up identically for the same product independently of who is phrasing the FU and independently of when or where it is phrased, Collado-Ruiz and Ostad-Ahmad-Ghorabi (2010b) developed the concept of fuons (short for functional icon). A fuon is an abstraction of a product, based on its essential function; it represents the whole set of products that share the parameters for its functions' flows. Fuons aim at standardizing FUs, making different experts deliver the same parameters to phrase them. Collado-Ruiz and Ostad-Ahmad-Ghorabi (2010b) also showed how fuons would act in the phrasing of FUs, and up to which point the output was standardized.

Apart from fuons, the authors have found very few other approaches that discuss in depth the definition of the FU (Cooper 2003). In most cases, the focus tends to be case-specific, in an attempt to solve the problem at hand, rather than develop on how the functional unit would be applicable for whole group-ranges of products.

The FU must be understood as a set of parameters (or Functional Unit parameters, *FUps*) that can be assessed and used for scaling and selecting the appropriate LCP-family. In order facilitate scaling and selection, it is important to distinguish between following types of *FUps*:

- Physical units, further indicated as FUp^{p}: These are parameters which describe the main function of the product. They have physical magnitudes, hence values which allow scaling.
- Functional constraints, further indicated as FUp^{c}: Here, the distinction between two types is necessary - constraints that can be measured, indicated by FUp^{c1}, and those which can not be measured, indicated by FUp^{c2}. $FUp^{c1}s$ can be taken to compare between products and further to select the most similar for a LCP-family. $FUp^{c2}s$ can be measured as a dichotomy or from a limited list to select the products with most similar traits

LCP-families can be established by grouping products which have the same *FUps* together. For products with the same main functions, the according fuon can be selected and the included parameters need to be defined. The parameters cover a variety of products, but the FU of each specific product can be set up by using the parameters of the fuon. This way, it can be made sure that no relevant parameter for the FU is left out, and that all important aspects and specifications of the product are represented in the FU. Fuons facilitate the establishment of LCP-families through $FUp^c s$, and their scaling for benchmarking through $FUp^p s$. The creation of a systematic framework for the development of new fuons should therefore constitute a step in easing the generation of new fuons, and through that make it possible to apply them to everyday work and benchmarking in new product development.

One of the fortes of the concept was that the users, normal designers with no particular training in LCA or FU, could easily select the correct fuons out of a predefined list. Users were provided with descriptions of the fuons to detail their FUs accordingly. The development of such descriptions is however a time-consuming and delicate task that must be performed by somebody with environmental knowledge and product information at hand. Even when such information is available, structuring information in the correct way is not a trivial task.

For that matter, the authors present in section 2 a systematic framework that will structure and ease the development of fuons by such experts. Furthermore, consistency and validity checks will be presented, so that experts can assess up to which point the selected parameters meet the specifications for scaling of environmental information and development of benchmark reference ranges. This information is complemented by a case study in section 3, in which the development of two fuons – container products and logistic-intensive elements or services – is explained in detail, as well as their validity and scaling suitability.

2 MATERIALS AND METHODS

One of the main advantages of fuons is the fact that they dissociate their development – and accordingly the need for environmental background and product information – and their use. The latter was proven to be easier and more robust for setting up FUs (Collado-Ruiz and Ostad-Ahmad-Ghorabi 2010b). Nevertheless, the development still holds as a time-consuming and delicate task. It generally requires some level of knowledge of the market, as well as of products that are generally presumed to be very different to the product at hand, e.g. tables and beds. Disregarding secondary functions, the main functionality in both cases is to support matter in a particular – generally vertical – position, although their markets are relatively decoupled.

It is not enough to have information about these markets, it also has to be structured in a correct way and parameterized in order to make results inferable from its data. For that, $FUp^p s$ and $FUp^c s$ will have to be valid to scale and select respectively in a functional domain:

- Scalability is dependent on an enough number of $FUp^p s$, and also on the validity of a linear regression model based on them. Statistical indicators will be calculated and assessed for such model to ensure this (Collado-Ruiz and Ostad-Ahmad-Ghorabi 2010a).
- Representativeness for all products can be ensured if enough documentation is consulted. Therefore, the listing of products and the gathering of information must be exhaustive, and for every Product Design Specification (PDS) parameter or difference between products there should exist a FUp^c that explains it.

Therefore, sources of information for this process – to be gathered beforehand – include market studies with different parameters, PDS documents for the products and sources for inventory information. There is a need for a systematic stepwise approach to ensure such properties for all developed fuons. Steps to be followed should be (Figure 1):

1. Initial definition: an initial description of a fuon can be derived by taking the main flow or flows of a product into account. Flows to be addressed in this context are the flows for Materials (M), Energy (E) and/or Information (I), as is done by some functional analysis methods (Pahl and Beitz 1996, Ullman 1997, Bytheway 1992). If more than one main flow is accounted for the

product, more than one fuon should be developed for the product. To gain generality, all possible products with the same main flow should be listed. Creativity techniques such as brainstorming can help on this endeavor. Market studies should be carried out to get more information about technical parameters for each of these products. When possible, the PDS should be consulted.

2. Definition of $FUp^p s$: They should describe the physical nature of the products, out of their main function. Should this not be enough, a screening of the PDS might help to define all necessary $FUp^p s$. It is encouraged at this point to state as many as possible: their individual validity will be statistically checked for scaling, as will be explained later. However, attention should be paid in their independence.
3. Definition of $FUp^c s$: They are directly derived from the PDS. Removing the specifications used for the definition of $FUp^p s$, many of the remaining requirements of the PDS can be used for $FUp^c s$. $FUp^c s$ defined as constraints with a magnitude will constitute $FUp^{c1} s$, and those of being specified without any magnitude will be considered $FUp^{c2} s$.

Step 2 includes a statistical check of whether the chosen candidates for the $FUp^p s$ are able to describe the products (Figure 1). A linear regression model needs to be set up in order to judge whether the $FUp^p s$ can serve as a suitable predictor for the environmental impacts. The linear regression model will have $FUp^p s$ as independent variables, being dealt as scaling parameters. The dependent variable will be environmental impact, either through an indicator for a key environmental impact (e.g. CO_2 for GlobalWarming Potential) or through a single score (Goedkoop et al 2004). The quality of the regression model can be investigated by considering the following (Bosch 2005, Hackl 2004):

1. For each FUp^p the probability of error p should remain below 0.05 ($p \leq 0.05$, significance level 5%). This criterion implies that 95% of the environmental impacts can be described by this variable. Nevertheless, it is not always possible to meet this criterion. In such cases the chosen FUp^p should minimize the p-value.
2. The coefficient of determination R^2 of the linear model should be greater than 0.35 and preferably as close to 1 as possible.
3. To judge the influence of outliers, the residuals of the model need to be evaluated as well. Residuals should have a normal distribution. Conducting a Kolmogorov-Smirnov test (Berger and Zhou 2005) and making use of histogram and normal curve plots help to check for normality of residuals.

The p-value of the $FUp^p s$ influences R^2 and the p-value of the residuals, and indicates the suitable independent variables for the LCP-family. Those LCP-families can be established from products described by the fuon, among those with common $FUp^c s$. Within them, $FUp^p s$ will serve as scaling parameter.

When more than one fuon is needed to define a product, all *FUps* are to be considered. If there are common parameters, they shall only be accounted once. Statistical analysis can also point out couplings between $FUp^p s$, by which at least one of them will be removed from the model.

Algorithm in Figure 1 can develop any fuon that defines a specific product. Ideally, it would be linked to a larger number of products. It is possible, however, that the list of candidate products is extended afterwards. The fuon should still hold valid – if the initial search or brainstorming has been done correctly – although possibilities include extending the list of $FUp^c s$ to cover for the differences and categorization due to this.

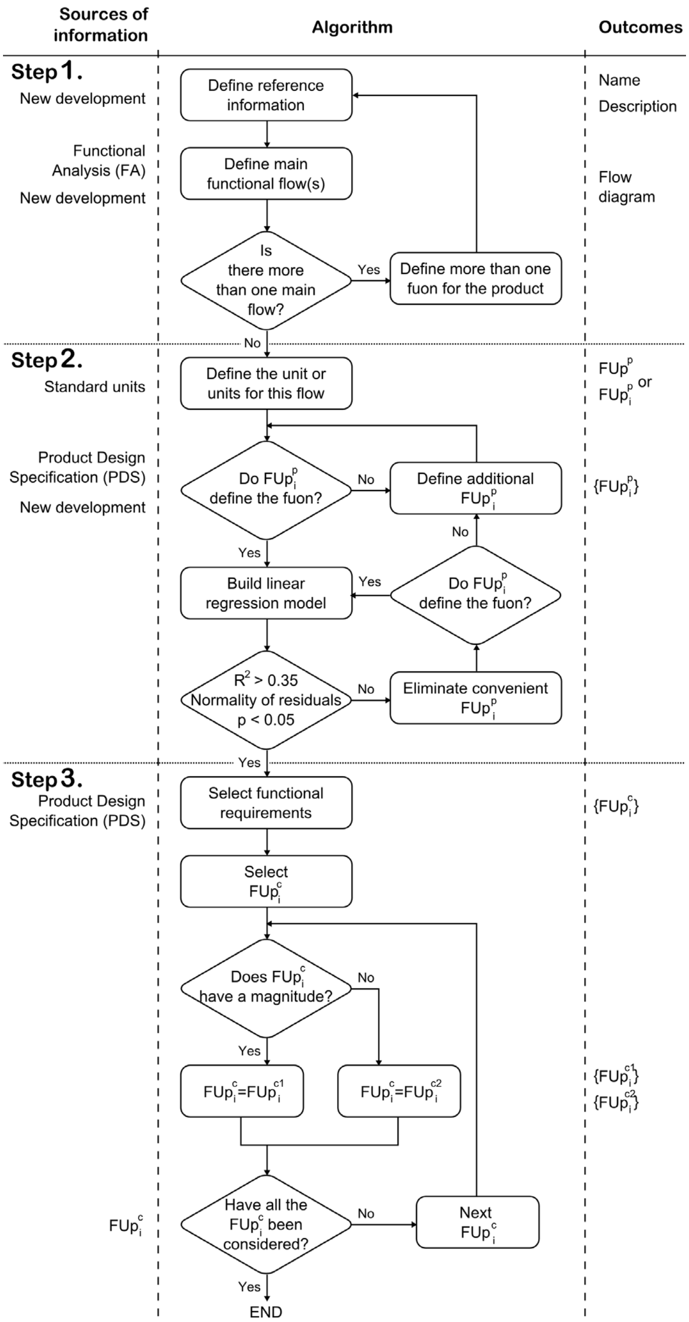

Figure 1. Algorithm to develop a fuon

3 CASE STUDY OF THE SYSTEMATIC DEVELOPMENT OF TWO FUONS

A case study has been developed to show that, with the proposed approach on Figure 1, one can develop fuons from a widespread variety of products who share a common functional flow, and draw conclusions from their LCA results through LCP families. This case study will cover packaging elements, such as bottles or boxes. These products share a common main function of containing matter. Step 1 is to name and define this fuon. Since the common characteristic is that they all contain matter, it will be called physical container, hereon referred as container. It is described as an element that encloses partly or totally other physical elements, protecting them or isolating them from the external environment. The apparent basic functional flow is matter. This matter – whatever is introduced in the container – is stored in the container until it is required by the user who then extracts it. A list of 52 of such products with variations in size and/or type, was modeled. It included 18 different bottles, (varying from 0.2l to 1.5l, including glass, PET and PP bottles for single and/or multi-use), 5 cans (drinking and food cans, different in size and material composition), 6 different

Tupperware (variation in size), 4 different freight containers (twenty-foot and forty-foot equivalent), 6 envelope letters different in size, 3 different trash cans, 6 bags (plastics bags and paper bags, with and without handles) and 4 boxes (pizza box and cardboard boxes different in size).

However, some products are not completely defined by the container fuon. Some of the products, e.g. some of the glass bottles or the freight containers, are used more than once in their life cycle. Some other, such as the envelopes might be single use, but they will be transported over more or less long distances. Finally some others might be multi-use, but not need to be transported over distances, such as the trash cans. The fuon container (or the mere content of matter) is not able to cover the fact of the need to more or less transportation, which for some of the products constitutes the main reasons of existence. Hence logistics must also be considered for some of them. As it is an independent basic functional flow (movement of matter), the effects of logistics will be covered by an additional fuon.

Since the characteristic of this additional fuon is to move matter from one point to the other from a service point of view, the fuon will be named *logistics-intensive element*, further named as *logistics*. It is described as *an element with the intention to allow transportation, protecting and allowing the necessary stacking or manipulation*. The only existing flow is matter. This matter is moved from one point to the other. It is a function for the provider/company, not for the product. In other words, it is not the product providing the possibility to move, but the product needs to be moved from one point to the other to fulfill its function.

The first fuon to be further developed is the container fuon. In step 2, the main flows are defined and parameterized. As standard unit, containers tend to be defined by the quantity of matter they contain. A closer look reveals that the limiting factor tends to be the volume contained (V), being the mass adaptive to the physical characteristics. Nevertheless, some containers will be under stricter mechanical specifications than others, as can be seen in the variation of their PDS. Therefore, there is a need for additional variables to be defined as FUp^p. A first estimation for a second FUp^p is the maximum stress requirement (σ). This second variable must be calculated as the ratio between the weight to be lifted and the active surface holding that part. Surely many other parts of the product such as handles or walls will be subject to stricter requirements. Nevertheless, this is something dependent on the design decisions. Since no assumption of technical solutions can be made at this point, this will be considered at a later stage as technical variables (and not functional ones, as is being defined here).

The units selected for the description of the FUp^ps of the fuon were derived units from the metric system: dm^3 *(liters)* and N/mm^2 *(MPa)*. These FUp^ps have to be tested for validity. The life cycle inventory was developed for all products, and their environmental impact was assessed by using Cumulative Energy Demand (in *MJ*) for each material or process involved in the life cycle. Furthermore, for each one of them, the previously mentioned FUp^ps were defined according to the specification.

To check the usefulness of the fuon, as explained in section 2, a linear regression model was developed with FUp^ps as independent variables, and environmental impact as dependent variable. If such a model is possible and significant, then it should be possible to develop representative LCP-families from it (Collado-Ruiz and Ostad-Ahmad-Ghorabi 2010a). All the products which were identified as being logistics-intensive were sorted out.

Nineteen products were then remaining. Significance of FUp^ps was tracked by using statistics software SPSS. The results of the analysis in Table 1 shows that *Volume* constitutes a suitable scaling factor ($p \leq 0.05$), whereas *Stress requirement* does not allow scaling based on the linear regression model. Nevertheless, the residuals of the model followed a normal distribution ($p=0.815$).

Stress was removed from the list of candidates for FUp^ps. To find a representative related alternative, potential FUp^ps which influence stress requirements were sought. Within this frame, the *Weight supported*, hence the weight contained in the container, and the *Number of storages*, were taken into account. This deductive approach was then verified as previously described by using a linear regression model (Table 1 – Model 2). Although the stricter requirement of $p \leq 0.05$ is not met, the chosen variables minimize the p-value for the model and can therefore be regarded as good enough parameters for a comprehensive model. Figure 2a shows a histogram of the residuals of the model and compares it with a normal curve. Figure 2b shows a P-P plot indicating outliers. The Kolomogorov-Smirnov test gives $p=0.982$ and proves a normal distribution of the residuals. The three variables *volume contained, weight supported* and *number of storages* proved suitable for scaling among the investigated products.

Table 1. Properties of the first model for the container fuon

Model 1		Model 2	
$N = 19$ $R^2 = 1$		$N = 19$ $R^2 = 1$	
	p		p
Volume	0.000	Volume	0.000
Stress	0.53	Weight supported	0.117
		Number of storages	0.138

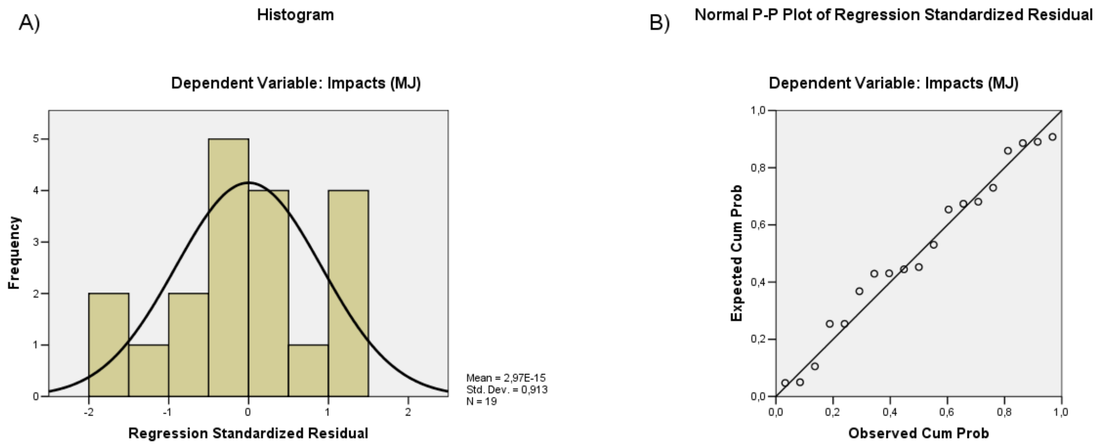

Figure 2. Plot of statistics for Model 2 of the fuon

FUp^{p}s do not define the product completely: other characteristics must be specified for products to comply with the needs of the user. In step 3 the PDS document of several of those products was scanned to detect additional requirements that will take the form of *FUp^{c}s*. Since the fuon container includes a wide variety of products, a workshop was performed to add any additional requirements of these other products. The resulting list is shown in Table 2. They were categorized as was presented in section 1.

Table 2. List of defined FUp^{c}s for the contanier fuon

Thermal max temp	Additional magnitudes	*FUp^{c1}*
Thermal min temp		
Thermal insulation	Scalable subjective constraints	
Hygiene constraints		
Mechanical constraints		
Dimension constraints		
Dielectric insulation	Requirements as dichotomies	*FUp^{c2}*
Infrared/ulatraviolet filtering		
Corrosion constraints		
Transparency		
Watertight/ Airtight		
Closable		
Information content		

The logistics fuon must also be developed. Since it does not have more than one main flow (not considering the container flow), it is then possible to describe it by means of one fuon. In step 2, the parameters, which are decided to describe the fact of transportation, are the *distance to be covered* (in *km*), the *effective weight load* (in *kg*) to be transported and the *number of trips*. By using these three parameters as *FUp^{p}s*, not only products being moved can be modeled, but also logistics as a service.
Since in the list both fuons are coupled, a set of new analysis can be done at this point. The previously excluded logistic-intensive products of the case study can be taken into consideration, carrying out

analysis with all 52 products. Again, the significance of the FUp^ps was tracked to analyze suitability. Several cases were investigated:

- All 52 products were considered and the fuon logistics was applied (therefore, only *N=33* cases were valid): the three FUp^ps of the fuon logistic constitute suitable scaling factors for all products: Distance *p=0.001*, Effective weight load *p=0.000*, Number of trips *p=0.076*, $R^2=0.971$. However, the residuals are not distributed normal (Kolmogorov-Smirnov test $p=0.000 < 0.05$). The reason for that was found in the inventory of the freight containers, which have outstandingly high values for both, the weights to be supported and the distances to be covered compared to the other products in the group. They constitute outliers to the linear regression model. An approach could be to remove these products from the list of products being investigated and include them in a group, which have the same range of quantities. In a practical case, this is analogous to them being filtered out from the rest of the group because of having very different FUp^cs. For the remaining *N=29* cases, the model turns to be: *Distance p=0.381, Effective weight load p=0.003*, *Number of trips p=0.000, R2=0.984.* The Kolmogorov-Smirnov test gives *p=0.143* and proves a normal distribution. The p-value for the variable Distance does not meet the stricter requirement of $p \leq 0.05$, it can be disregarded for the specific set of products investigated.
- All 52 products were considered and both fuons, container and logistics were applied (*N=33* cases were valid including the freight containers): The FUp^ps *Weight supported* and *Effective weight load* are similar and the model pointed out the irrelevance of having both. Same applies to *Number of storages* and *Number of trips*. The latter two were removed from the model, as they did not constitute suitable variables to describe the linear model (*p=0.793* and *p=0.794*). The remaining variables constitute suitable parameters with *p=0.000*. However, due to outliers, the residuals are not normal distributed (*p=0.000*). Once again, removing the freight containers, *N=29* products remain for investigation. Again, the model points out the irrelevance of havingWeight supported and Effective weight load on the one hand and Number of storages and Number of trips on the other hand at the same time. Also, *Volume* turns to be an insufficient predictor now with *p=0.803* as well as *Distance* with *p=0.376*. The remaining variables *Weight supported* (*p=0.004*) and Number of trips (*p=0.000*) constitute suitable parameters for the linear regression model. The residuals follow a normal distribution (*p=0.089*).
- All 52 products were considered and the fuon container was applied: *Volume p=0.000*, *Number of storages p=0.000, Weight p=0.048, R2=0.992.* The three FUp^ps constitute suitable scaling factors for all products. However, the residuals are not normal distributed. Even when outliers are identified and removed from the model, the distribution of the residuals does not turn to be normal. In fact, no suitable combination of a set of products and FUp^ps could be found which lead to a normal distribution of residuals. This shows that more than one fuon is needed to describe all 52 products. For the logistics fuon, step 3 was carried out as well by analyzing PDS documents and different reports. The derived FUp^cs are listed in Table 3. Since there are no dichotomic or classifying FUp^cs, only $FUp^{c1}s$ are defined for this fuon.

Table 3. List of defined FUp^cs for the logistics fuon

Speed requirements	Additional magnitudes	FUp^{c1}
Protection	Scalable subjective constraints	

Furthermore, to check the validity of FUp^cs, the model was also tested filtering through them. For each developed scenario, at least one of the FUp^ps turned out to be relevant for the elaboration of a model. In most cases, most of the FUp^ps took part. Therefore, for all the studied combinations, it was possible to generate a model that was representative enough of the environmental impact, with a reliability of 80%.

4 DISCUSSION

This paper has presented a systematic framework by which it is possible to develop new fuons (Collado-Ruiz and Ostad-Ahmad-Ghorabi 2010b). This should allow the creation of a greater set of them, so that they can be effectively used to model larger groups of products or, on a midterm time

scope, to model all products. Furthermore, following the proposed steps also ensures that the developed fuons will have a similar form once in use.
The authors are conscious that a systematic framework cannot be strictly proven, and therefore the case study in this paper seeks to give a vision on how this framework performs. It shows the applicability through the development and analysis of two fuons. They serve both as showcase of the possibilities of applying the framework, and as example for potential practitioners that are willing to develop fuons in their industries.
In any case this stepwise approach provides the possibility of planning and developing new fuons. The applicability of the systematic framework was tested through three workshops: One group was composed of experts in design, with no environmental background; the other two groups were composed of students with technical background. The workshops included a short introduction on fuons and the systematic framework. Within a limited time scope of 30 minutes for the workshop, it was observed that all three teams succeeded in developing a common understanding of the concept and getting a vision of the terminologies used in the concept. Also, team members were able to agree on the goal and scope definition of a project plan for the development of a new fuon, in particular for the product example of a motor given in the workshop.
The concept of fuons is currently being implemented into a web-based software in the scope of an industrial-based research project. This software will serve as a first approach to retrieve drawings directly from CAD systems, to provide fuons in order to scale environmental information in the scope of LCP-families and to show results to the engineering designer. This project also includes the development of more fuons through applying the systematic framework presented here.
One of the issues that arose during the development of this framework was the necessary level of detail. When is the list of products enough? 52 products were taken in the example, out of the fact of having all expected variety represented. However, a greater database might have yielded an additional FUp^c. As this can never be ensured, the option of ”further detailing” was conceived in the algorithm, although it should be avoided.
Fuons have been applied here to a subset of simple products. However, the complexity of products in which it could be applied may vary considerably. One such case of complex products was presented in (Ostad-Ahmad-Ghorabi et al 2013). In that case, even if the development took into consideration more environmental information, the main functions were still able to be modeled in a small set of parameters. A further line of development could be the study of the additive property of fuons, together with an assessment of how many fuons would make sense in the assessment of one only product.
This paper therefore aims at opening the doors for all researchers and practitioners to develop and share their fuons. This would expectedly create a common understanding on FU definition and of scaling of environmental information for benchmarking.

REFERENCES

Bosch K (2005) Elementare Einführung in die angewandte Statistik, 8th edn. Vieweg+Teubner
Brezet H, Van Hemel C (1997) Ecodesign: a promising approach to sustainable production and consumption. United Nations Environment Programme, UNEP
Bytheway C (1992) FAST - an intuitive thinking technique. In: Proceedings of the 1992 International Conference for the Society of American Value Engineers (SAFE), Society of American Value Engineers, Phoenix, USA
Collado-Ruiz D, Ostad-Ahmad-Ghorabi H (2010a) Comparing LCA results of competing products. developing reference ranges from a product family approach. Journal of Cleaner Production 18(4):355–364,
Collado-Ruiz D, Ostad-Ahmad-Ghorabi H (2010b) Fuon theory: Standardizing functional units for product design. Resources, Conservation & Recycling 54(10):683–691,
Cooper J.S. (2003) Specifying functional units and reference flows for comparable alternatives. The International Journal of Life Cycle Assessment. 8(6): 337-349, 2003
Coulter S, Bras B, Foley C (1995) A lexicon of green engineering terms. In: International Conference on Engineering Design (ICED), Praha
Ernzer M, Birkhofer H (2003) Environmental impact assessment in design or is it worth to carry out a full LCA. In: Proceedings of the 14th International Conference on Engineering Design, August 2003, Stockholm
Ernzer M, Grüner C, Birkhofer H (2001) Implementation of DfE in the daily design work-an approach derived from surveys. In: Proceedings of 2001 ASME Design Engineering Technical Conference (DETC 2001)

Erzner M,WimmerW(2002) From environmental assessment to Design for Environment prod uct changes: an evaluation of quantitative and qualitative methods. Journal of Engineering Design 13(3):233–242
Germani M, Mandorli F, Corbo P, M Mengoni M (2004) How facilitate the use of LCA tools in SMEs - a practical example. In: Proceedings of 12th SETAC Europe LCA Case Studies Symposium, pp 163 – 166
Goedkoop M, Oele M, Effting S (2004) SimaPro database manual methods library. PRé Consultants B.V., Netherlands
Hackl P (2004) Einführung in die Ökonometrie. Pearson Studium, München
Heijungs, R, Suh, S (2002) The computational structure of life cycle assessment. Kluwer Academic Pub
HoffmanW(1997) Recent advances in design for environment at motorola. Journal of Industrial Ecology 1(1):131–140
Howarth G, Hadfield M (2006) A sustainable product design model. Materials & design 27(10):1128–1133
ISO I (2006) ISO 14040. Environmental management - Life cycle assessment - Principles and framework (ISO 14040:2006). CEN (European Committee for Standardisation), Brussels
Jeswiet J, Hauschild M (2005) Ecodesign and future environmental impacts. Materials and Design 26(7):629–634
Jönbrink A, Wolf-Wats, C, Erixon M, Olsson P, Wallén E (2000) LCA software survey. Tech. rep., Industriforskningsinstituten i Sverige-IVF, IVL B 1390.
Karlsson R, Luttropp C (2006) Ecodesign: what's happening? an overview of the subject area of ecodesign and of the papers in this special issue. Journal of Cleaner Production 14(15-16):1291–1298
Kobayashi Y, Kobayashi H, Hongu A, Sanehira K (2005) A practical method for quantifying eco-efficiency using eco-design support tools. Journal of Industrial Ecology 9:131–144
Berger V.W., Zhou Y.Y (2005) Kolmogorov–Smirnov Tests. Encyclopedia of Statistics in Behavioral Science, Wiley Online Library, 2005
Lenzen M, Treloar G (2003) Differential convergence of life-cycle inventories towards upstream production layers. Journal of Industrial Ecology 6(3–4):137–160
Lindahl M (2005) Engineering designers' requirements on design for environment methods and tools. PhD thesis, Kungliga Tekniska Högskolan (KTH), Stockholm
McAloone T (2003) Demands for sustainable development. In: Proceedings of The 14th International Conference on Engineering Design (ICED'03), Linköping, Sweden, pp 19–21
Millet D, Bistagnino L, Lanzavecchia C, Camous R, Poldma T (2007) Does the potential of the use of LCA match the design team needs? Journal of Cleaner Production 15(4):335–346
Ostad-Ahmad-Ghorabi H, Schäfer T, Spielauer A, Aschinger G, Collado-Ruiz D (2013) Development of the Digital Storage Fuon. Proceedings of the 19th International Conference on Engineering Design (ICED13), Design for Harmonies. 2013 (2): 133-142. ISBN: 978-1-904670-45-2
Pahl G, Beitz W(1996) Engineering design: a systematic approach. Springer Verlag, translation by Wallace, K. and Blessing, L. & Bauert, F.
Sousa I, Wallace D (2006) Product classification to support approximate life-cycle assessment of design concepts. Technological Forecasting & Social Change 73(3):228–249
Ullman D (1997) The mechanical design process, 2nd edn. McGraw-Hill
Waage S (2007) Re-considering product design: a practical "road-map" for integration of sustainability issues. Journal of Cleaner production 15(7):638–649
Wenzel H, Hauschild M, Alting L (1997) Environmental Assessment of Products, Vol.1: Methodology, tools and case studies in product development. Chapman & Hall, London, UK