21ST INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED17
21-25 AUGUST 2017, THE UNIVERSITY OF BRITISH COLUMBIA, VANCOUVER, CANADA

ENVIRONMENTAL IMPACTS DURING THE PRODUCT USAGE - IDENTIFICATION AND CATEGORISATION OF INFLUENCING FACTORS

Kattwinkel, Daniela; Herzog, Michael; Neumann, Marc; Bender, Beate
Ruhr University Bochum, Germany

Abstract

To respond to environmental sustainability challenges, many industries are now facing pressure to improve their environmental performance. A developmental approach that systematically integrates an environmental consideration along the entire product life cycle is called ecodesign. To promote an effective ecodesign application, companies need to recognise their products' inherent potential for environmental improvements early in the development process. This paper represents the first step in that direction by analysing the environmental impacts during the usage phase. Thereby every usage process is characterised by different determinants that influence it. On the basis of a literature review, 72 factors that influence the environmental impacts during usage phase are presented in this paper. The influencing factors are structured according to the system elements of a socio-technical system in relation to its properties. Furthermore, every factor is quantitatively or qualitatively differentiated. Using the example of a refrigerator, the influencing factors are evaluated according to their specific impact on the environment.

Keywords: Ecodesign, Sustainability, Early design phases, Design for X (DfX), Usage phase

Contact:
Daniela Kattwinkel
Ruhr University Bochum
Chair of Product Development
Germany
kattwinkel@lpe.rub.de

Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 21st International Conference on Engineering Design (ICED17), Vol. 1: Resource-Sensitive Design | Design Research Applications and Case Studies, Vancouver, Canada, 21.-25.08.2017.

1 INTRODUCTION AND MOTIVATION

The reduction of the resource consumption and the decrease of emissions are European as well as global targets (European Commission, 2011). To realise this transformation, new or ameliorated products and services are necessary. Especially the development of environmentally sound products and services poses a complex challenge, because a multitude of competitive technical, economic and ecological requirements must be considered (Abele et al., 2008). A developmental approach that jointly considers these requirements over the entire product life cycle without compromising other essential product characteristics such as functionality, performance, quality or cost is called ecodesign (Johansson, 2002). Over the past decades, numerous ecodesign methods (e.g. Design for Energy Efficiency), tools (e.g. SoldikWorks Sustainability) and standards (e.g. ISO 14040) have been developed (Rossi et al., 2016). Most ecodesign approaches however lack acceptance and application in the industry (Pigosso et al., 2015). Barriers for the use of ecodesign are for example the abundance and specificity of methods and tools as well as the additional resources required in terms of budget, personnel, time and data (Rossi et al., 2016). In order to justify the resulting additional effort, a company has to estimate a product's potential for reducing the environmental impact, preferably early. Therefore, it is crucial to understand which kind of products exhibit a high ecodesign potential and for which products it is not economically worthwhile, because a company will not make a decision that is not primarily economically motivated (Byggeth and Hochschorner, 2006). Many technical products have a significant potential for being ecologically amended "in order to reduce the environmental impacts and to achieve energy savings through better design which also leads to economic savings for businesses and end-users" (European Commission, 2011).

During the design process, a product's function, its operating principles, shape and material are selected and with that, the most prevailing technical, economic and ecological product properties are defined. On this account, environmental protection must start with the product development. To consider and to optimise the environmental product properties at an early stage during the product development is the basis for a targeted and efficient development of environmentally sound products (Oberender, 2006). Johansson (2002) even argues "that environmental issues should be considered at the very beginning of the product development process". In these early stages, the cost of any environmental intervention is at its lowest and most flexible (Bhamra, 2004). Figure 1 qualitatively illustrates the relationship between the determination of environmental impacts and the actually caused environmental impacts during a product's lifecycle. Evidently, there exists a time lag between the determination and the emergence of the impacts in the environment. This highlights the importance of estimating and considering environmental aspects during the development phase, in which "the design freedom decreases in relation to the product development process and time" (Byggeth and Hochschorner, 2006).

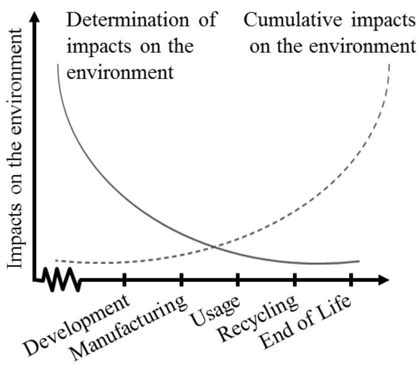

Figure 1. Definition and development of environmental impacts (Dannheim, 1999)

Until now, most approaches in research and in the industry, focus on the life phases "Manufacturing", "Recycling" and "End of Life" (Oberender, 2006). The directive 2009/125/EC, a European framework for the setting of ecodesign requirements for energy-related products is the first guideline that explicitly takes the resource consumption of products during their usage into account (The European Parliament and of the Council of the European Union, 2009). But especially the usage phase offers a great potential for ecological improvements, because for many technical products the usage phase is the most impacting

of the life cycle phases. Depending on the degree of efficiency, the usage of a refrigerator for example accumulates to 90% of its primary energy consumption and about 84% of its overall environmental impacts (Ma et al., 2012; Ruedenauer, 2006). An analysis of the usage phase in order to minimise the environmental impacts is only valuable for those products which actively cause environmental impairments during the usage. Dannheim (1999) therefore differentiates between active (e.g. power drill, coffee machine) and passive products (e.g. paper weight, scissors). According to that differentiation this publication focuses on active technical products.
Until now, there exists no systematic evaluation possibility for the ecodesign potential of technical products during their usage. As a first step, factors that influence the resource consumption during the usage need to be identified. Afterwards product specific usage profiles can be generated and serve as a basis for the categorisation of different products according to their ecodesign potential. Companies may then easily estimate their products' ecodesign potential and reassess a further development to reduce the environmental impacts. The aim of this publication is to identify factors that influence a product's resource consumption during its usage and to present a scheme to categorise these factors.
Following the Design Research Methodology by Blessing and Chakrabarti (2009) the 'descriptive study I' investigates the importance of the usage phase from a product developmental view (Section 2). In the 'prescriptive study' factors that influence the usage of a product are identified, categorised and specified (Section 3). The results are then demonstrated using a refrigerator as an example (Section 3.4).

2 THE IMPORTANCE OF THE USAGE PHASE

Every process within the life cycle of a product is associated with specific environmental impacts. Therefore, a solely technical and engineering based knowledge is not sufficient for the development of environmentally sound products. It is rather necessary to acquire an extensive knowledge about the product life cycle phases and their processes (Oberender, 2006) (see Figure 2).

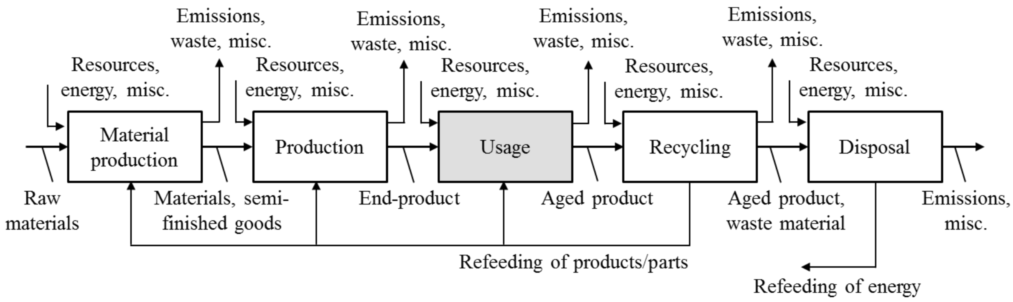

Figure 2. Product life cycle with material and energy flows (Grüner, 2001)

In the different subject areas that take a part in the development of environmentally sound products, there exist varying definitions and interpretations of the product life cycle. However, a broad agreement has been established over its division in five main phases (Grüner, 2001). The main difference lies in the level of consideration of transport processes. In this paper, the transport is not seen as an independent phase but rather as recurring processes that take place within a phase and in between them. Figure 2 illustrates a generic product life cycle including the material and energy flows. From a product or process developmental view the product changes its role during the usage phase from an operand to an operator (Dannheim, 1999). So, the product then acts as an instrument for the transformation of input to output. Because products are produced in order to be used, the design of the usage phase and its processes is a key activity of every product development.
There exist numerous methods and tools to estimate the environmental impacts during the life cycle phases and with that also the product usage. These are for example the framework ISO 14040, the commercial software tools GaBi and SimaPro, the simplified life cycle analysis tools Quantis and Sustainable Minds as well as the web-based applications EcoMundo and EuP Manager (Rossi et al., 2016). Even though ecodesign is a significant research topic, most scientific approaches as well as

methods and tools do not concentrate solely on the usage phase[1]. This phase is mostly regarded in reference to the concept of Product-Service Systems or in optimisations of the life expectancy (Oberender, 2006). According to Dannheim (1999) the usage phase is especially significant because most of the environmental impacts accumulate during a product's usage (for household appliances up to 95%). In addition, the processes during the usage phase also influence processes in previous and subsequent life cycle phases.

2.1 Sub-processes within the usage phase

On a methodical level, there exists a divergence between the ecological relevance of the usage phase and the development of methods and tools for the support of the development (Oberender, 2006). Highlighting the ecodesign potential of products, requires a systematic and detailed analysis of the usage processes and their influencing factors. Within the following sections, two approaches for a systemisation of the usage phase are briefly explained.
Based on the analysis of approaches for structuring the usage in the construction methodology and environmental accounting, Dannheim (1999) and Schott (1998) developed a systematisation for the usage phase into partial phases. Figure 3 illustrates this systematisation and includes the alterations from Oberender (2006), who additionally divided the repair and shutdown phase. The present publication focuses the sub-phases 'Use', 'Service' and 'Repair'.

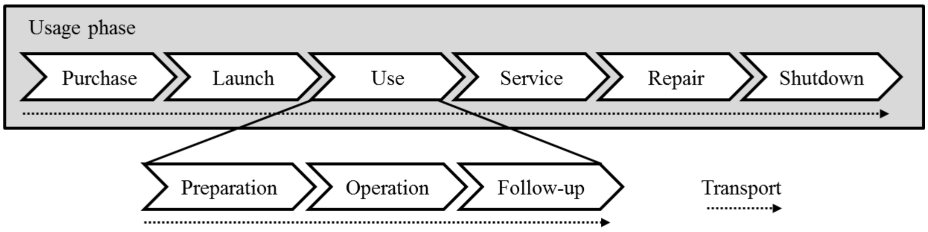

Figure 3. Systematisation of the usage phase (Dannheim, 1999; Oberender, 2006)

Serna-Mansoux et al. (2014) argue that in life cycle analysis the usage phase "is normally calculated considering both an average use and user". This generalisation limits the effectiveness of any attempts for decreasing a product's environmental impacts. For that reason, they propose a tool to model the usage phase very detailed through a differentiation between the user and the product contributions (Figure 4). So, the user contributes in form of the actions and the occurrence of the moments in which these actions take place. "By identifying which aspect of the product of user actions impacts the most" on the environmental performance, the tool can prioritise the redesign effort (Serna-Mansoux et al., 2014).

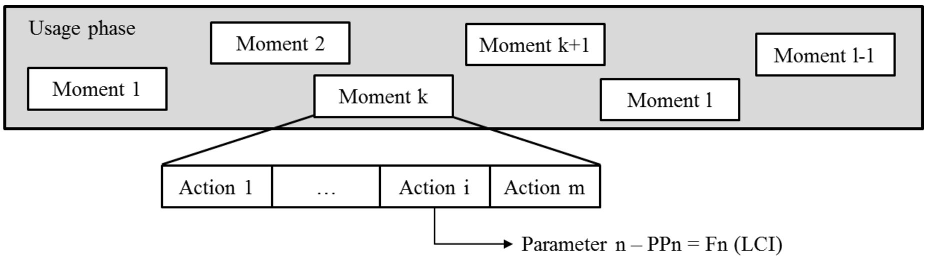

Figure 4. Model of the usage phase (Serna-Mansoux et al., 2014)

2.2 The influence of the user in the usage phase

Normally environmental impacts do not arise autonomously, but rather through the interaction between user and product. Therefore, the user behaviour is of central importance for the development of products. In order to realise the development of environmentally sound products, differentiated information about the product properties, the user and the task are necessary. Behaviour that is damaging to the

---

[1] With the exception of the Technical University of Darmstadt, where several doctoral theses have explicitly focused on the usage phase in connection with the development of environmentally sound products (Dannheim, 1999; Oberender, 2006).

environment, may result from maladjustments between the user and the product (e.g. insufficient ecological knowledge), the user and the task (e.g. insufficient knowledge about the fulfilment of a task) as well as the task and the product (e.g. product not suited for the task) (Wiese et al., 2004). Because every usage is afflicted with negative impacts for the environment, a possible definition for a usage maloperation as a dimension of the environmental consequences is not permissible. It is rather necessary to distinguish the usage behaviour into four categories (Dannheim and Birkhofer, 1998; Oberender, 2006):

1. Optimal behaviour represents the engineering / technologic usage behaviour with the minimal environmental impacts for a given product and a given task.
2. Misbehaviour is any deviation from the optimal behaviour.
3. Real behaviour is the actual usage behaviour depending on the user, the product, the task and operating conditions.
4. Normal behaviour stands for a product depending expected of the real behaviour.

In actual usage activities, the real behaviour with a usage specific overlap of the optimal and misbehaviour will adjust. The extent of the proportional misbehaviour depends on the kind of product, on its design, on the operating conditions and on the user. Popoff et al. (2016) refer to usage ecodrifts for a non-optimal use by the user. Generally, the more complex a usage process is and the more a user can influence this process, the higher the portion of misbehaviour will be (Oberender, 2004).

3 IDENTIFICATION OF INFLUENCING FACTORS

Impacts on the environment during the usage processes are not only influenced by the properties of the product itself but also by the user behaviour, the energy, material or signal flows and the surrounding environment. Products (technical artefacts) as well as socio-technical systems (technical artefact + user) generally operate within an environment and not in isolation. Thus, such a system involves users who interact with it through input effects and the corresponding feedback effects, in order to realise the intended effects during the usage (Pahl et al., 2007). Apart from the desired inputs in form of energy, material or signal flows, additional external influences may affect the system and cause side effects on the user as well as on the environment. These interrelationships are illustrated in general and on the example of a refrigerator in Figure 5. During the development of technical systems, these interactions must be taken into account, in order to achieve the desired effects within the usage and to anticipate the side effects. External influences affect the user, the technical artefact and the entire socio-technical system. However, the usage is not only influenced by these external influences but also by the existence and amount of the energy, material and signal flows, by the characteristics of the technical artefacts (geometry, multi-functionality, etc.) and by the user (frequency, duration of usage, etc.). All these influencing factors have a great impact on the environmental performance of a socio-technical system.

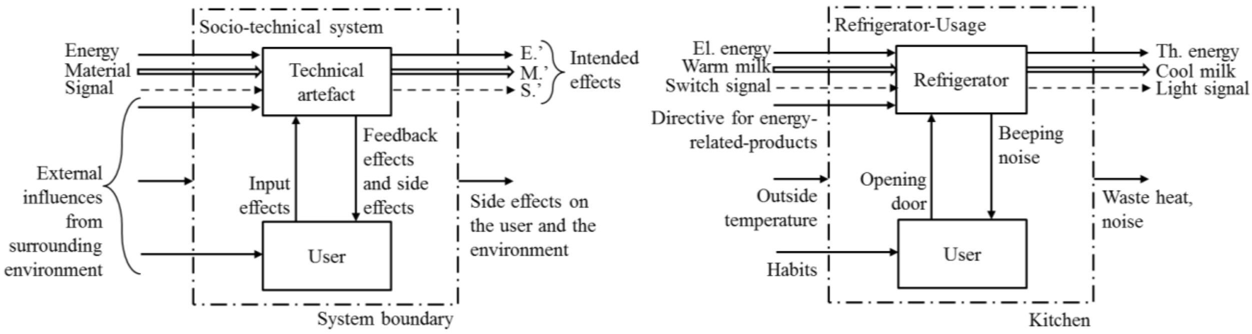

Figure 5. Interrelationships in socio-technical systems (according to Pahl et al., 2007)

Oberender (2006) systemises these influencing factors into internal and external product properties, user influence and general influencing factors. Internal properties are elementary and indivisible properties, that are selected by the product developer (e.g. choice of material), whereas external properties are defined as visible and measurable effects, that are determined by the internal properties (e.g. mass) (Hubka, 1984). Zhao et al. (2011) differentiate the terms independent and dependant properties. Similarly, within the concept of Property-Driven Development (PDD), characteristics, which describe the structure and components of a product, are clearly distinguished from properties, which summarise the product's behaviour (Weber et al., 2004). Within this publication, only the external or dependant

properties, that are a result of the chosen characteristics (internal or independent properties) are analysed in regards to their influence on the environmental performance of a socio-technical system.
Until now, most scientific research has focused on producing absolute rather than relative, ecodesign indicators (Cerdan et al., 2009). These specify absolute quantities e.g. kg of a certain material or kWh of used energy. In this way, products of the same kind can be compared easily. However, for products of completely different sizes this is not applicable. Cerdan et al. (2009) propose a set of quantitative ecodesign indicators, in which e.g. the weight of the reusable parts is related to the total weight of the product. But for the determination of these absolute and relative indicators a high quality of specific data is required. For companies this means to dedicate extra resources and time to environmental analysis, to provide economic resources and to dispose of a high quantity of data without knowing, if their product owns a high ecodesign potential (Rossi et al., 2016). In the end, the outcome of these analyses might indicate that a possible product enhancement does not or only marginally change its environmental impacts. So, that to decrease the environmental impacts in a long term, companies need to know for which products the application of ecodesign tools and methods results in a higher amount of prevented environmental consequences. Different products have to be categorised in relation to their ecodesign potential. This needs to occur based on individual product usage profiles, derived from the interaction of different factors of the socio-technical system during its usage. In a first step, factors that influence the usage will be identified in the following sections.

3.1 Literature research and proceedings

To identify the factors that influence the environmental performance of a product during its usage, a literature research has been conducted. Until now there exist no approaches that focus on the identification of ecological influencing factors during the usage. Within a first sighting, 91 factors could be identified by the authors as well as derived from the following works:

- Reference book: Ehrlenspiel and Meerkamm, 2013; Feldhusen and Grote, 2013.
- Doctoral thesis: Dannheim, 1999; Lasser, 2002; Oberender, 2006; Hanusch, 2011.
- Publication in journal: Wiese et al., 2004; Tukker 2004.
- Conference paper: Ma et al.,2012; Serna-Mansoux et al., 2014.
- Report research project: Grießhammer et al., 2007; Schlacke et al., 2015.
- Standards: DIN ISO 20282-1; DIN CEN/TS 16524; DIN EN ISO 14050; DIN ISO/TR 14062.

All previously discussed current state of research has been integrated into the collection of influencing factors. That includes for example the systematisation of the usage phase in Section 3.1, the influence of the user in Section 3.2.
The identified factors were analysed with regard to their congruence, grouped together based on which system element e.g. user or product they referred to and merged in case of identical content. After specifying or generalising the influencing factors to be on the same level of detailing, 72 influencing factors were selected (see Table 1). The proposed influencing factors as well as the clustering of factors are explained in the following section.

3.2 Clustering of factors

As in table 1 illustrated, within the columns the factors are clustered in regards to which system elements from the socio-technical system they refer to (technical artefact; user; energy, material, signal flows; surrounding environment). The rows are sorted according to different properties as well as in which form they can be estimated (qualitative or quantitative). The list of properties derives from some of the product properties Weber et al. (2004) identified for the PDD. In this way, each influencing factor correlates with one system element and one property category. They are systemised according to the following properties:

- Definite properties:
  - Properties that are inherent so the system elements. They are not influenced by the usage.
  - Examples: The factor 'Number of surrounding environments' describes for what number of environments the product is designed for. A household appliance like a refrigerator will for most part be used within a stable temperature range at the inside of a building. Whereas a car must be adaptable to diverse weather conditions from temperatures below -20°C up to +50°C and higher on wet, dry, muddy, dusty etc. surfaces.
- Functional properties:

– Properties that describe the functions of the socio-technical system. They are also not directly influenced by the usage process.
– Examples: The factor 'Standby function' indicates the existence of a standby or sleeping modus, in which the product reduces its energy and/or material consumption to a minimal level. The screensaver on a computer may is an example for a standby mode in which the computer cuts power to unneeded subsystems and minimises the energy supply to the RAM memory.

Table1. Allocation of influencing factors to system elements and properties (shaded for the example of a refrigerator)

		System elements			
Properties	**Estimation**	**Technical artefact**	**User**	**Energy, Material, Signal flows**	**Surrounding environment**
Definitive properties	**Quantitative**	Individual life expectancy	Number of Users	Life expectancy of auxiliaries	Number of surrounding environments
		Technical life expectancy	Age	Energy consumption in downtime	Dependence on trends
	Qualitative	Reliability	Environmental motivation	Reusability of auxiliaries	Range of operating environments
		Availability	Qualification	Availability of data signals	Severity of physical environment
			Level of ownership	Material flow	Applicable laws, directives, regulations
		Contact to end-user			
Functional properties	**Quantitative**	Additional functions	Usage of additional functions	Amount of input signals	Availability of substitutional products
		Standby function	Usage of standby function		
		Automatic operation modus	Usage of automatic modus		
	Qualitative	Level of interaction	Level of interaction	Data signal for over use	Applicable safety tests, certificates
		Availability of safety stop	Health risk during usage		
Usage properties	**Quantitative**	Usage duration	Operating time	Energy consumption	Number of operating environments
		Availability			
		Level of product activity	Usage interval	Emissions	
			Operating duration		
			Interaction duration		
	Qualitative	Necessary usage preparation	Probability of usage preparation	Data signal for capacity	Applicable laws, directives, regulations
		Possibility of intentional maloperation	Probability of intentional maloperation		
		Possibility of unintentional maloperation	Probability of unintentional maloperation		
		Possibility of intuitive operability	Level of capacity utilization		
		Complexity of operability	Complexity of operability		
Service/Repair properties	**Quantitative**	Service interval	Probability of service	Data signal for needed service	Warranty laws
		Warranty duration			
	Qualitative	Service intensity	Probability of repair	Data signal for needed repairs	Availability of spare parts
		Reparability			
		Necessary cleanliness	Probability of cleaning	Data signal for needed cleaning	Cleanliness of direct environment
		Cleaning complexity	Disposal frequency		

Not applicable
Moderate influence
Slight influence
Strong influence

- Usage properties:
  – Properties that result from the actual and purposeful usage of the product.
  – Examples: The factor 'Probability of usage preparation' indicates to what likelihood the user will have performed all necessary preparatory processes, in order to use the product. This factor strongly depends on the user and the usage behaviour, cultural background, age, qualification

etc. For some products there is almost no usage preparation needed once it is installed e.g. a television. Other products like a vacuum cleaner, need to be transported to the location of the usage, the vacuum cleaner bag filling level has to be reviewed, the dust filter has to be controlled, the ground needs to be cleared of unnecessary objects etc. If the user is not willing to perform the required usage preparations, it may alter the entire usage phase of the product. Assumptions about the user and the usage behaviour can be made more accurate if more information about the user is present. For some products the target user is clearly defined e.g. devices for elderly people.

- Service/Repair properties:
  - Properties that describe measures to delay the shutdown or to restore a functional condition of the product. These are in some parts related to the usage properties.
  - Examples: The factor 'Data signal for needed service' indicates whether a service might be necessary, in order to guarantee full functionality. Some cars indicate for example that a change of oil after a certain mileage is obligatory. If this service is actually executed depends on the user, but a data signal that indicates a needed service may inform or motivate the user.

The same notation of an influencing factor can appear in multiple categories or for multiple system elements. For example, the technical artefact's "Availability" as a definite property represents the product's occurrence or presence for the costumer, whereas the "Availability" as a usage property stands for operational reliability (see Table 1). In the same way, the factor "Applicable laws, directives, [and] regulations" is valid as a definitive property for example for laws that concern the materials used within the product. In connection with the usage properties "Applicable laws, directives, [and] regulations" refer to the usage process for example in form of the directive 2009/125/EC for energy-using and energy-related products (The European Parliament and of the Council of the European Union, 2009).

3.3 Specification of factors

The listed factors may all influence a product's environmental performance during its usage. However individual products with differing usage properties are dissimilarly influenced by the factors. One factor that has a significant impact on one product's resource consumption, may not even slightly influence another's. A vacuum cleaner for example is strongly influenced by the factor "necessary cleanliness" (of technical artefact), because a full vacuum bag reduces the suction capacity to 12% (Dannheim, 1999). In contrast, a dirty interior will if at all slightly influence a refrigerator's energy consumption or capacity. In the case of the vacuum cleaner, the full vacuum bag will only impair the energy consumption if the vacuum cleaner is operated anyways. So only the interaction of the factors "necessary cleanliness" of the product, "usage interval" (how often) and "usage duration" (how long) causes a great negative effect. In conclusion, the influencing factors are not independent, they interact with and reinforce or reduce each other.

3.4 Exemplary detailing of factors

To clarify the categorisation and specification of the influencing factors, an exemplary estimation of a usage profile for a refrigerator has been realised (see shading of boxes in Table 1). Each influencing factors has been evaluated according to its influence on the environmental impacts. It can be differentiated between slight, moderate or strong influence as well as not applicable (if an insufficient amount of information is provided).

The example of a refrigerator was chosen, because of its high energy consumption during the usage phase. Statistically 115,3% of German households owned a refrigerator in the year 2003 (Rüdenauer, 2006). This product also demonstrates that through constant further developments as well as ecological frameworks and laws an averaged energy saving of 77% could be reached for refrigerators without freezing compartment in the last 25 years. But there is still a high potential for ecological improvements, because around 25% of the refrigerators are not used correctly and with that not in an energy efficient manner (Geppert and Stamminger, 2010). The following estimation of the influencing factors is based on the data that Rüdenauer (2006) acquired in a report funded by the German Federal Ministry for Education and Research about refrigerators and freezers and on a pan-European study about the influence of consumer behaviour on the energy consumption of refrigerators (Geppert and Stamminger, 2010). Exemplary valuations of the influencing factors will be briefly explained.

The factor 'Number of Users' has been estimated as a slight influence, because the number of users, if low or high will not remarkably influence the resource consumption. There is mostly more than one user for a refrigerator and that is already considered in the product concept. The "Qualification" of the users has a higher influence on the resource consumption, because through an improper filling of the refrigerator more energy is required to cool the content down to the desired temperature. In France 17.9% of households "never or only sometimes cooled down their [leftover] food before placing it in the refrigerator" (Geppert and Stamminger, 2010). The low 'Availability of substitutional products' has an even stronger influence. In the case of a vacuum cleaner, the user could sweep with a broom and reach a similar outcome. This does not apply for the refrigerator. There is only a limited possibility to substitute its functionality with a more environmentally friendly solution. On the other hand, a refrigerator does not produce any harmful emissions, except of heat during its usage. This specification of the factor 'Emissions' can therefore be declared as having a slight influence on the environmental performance. In the same way, the 'Possibility of intuitive operability' is not very important for the resource consumption of the refrigerator, because of its few functions and simple operation. Thus, it can be deduced, that it is difficult to falsely operate a refrigerator during the usage and with that this the specification of the factor can be estimated to have a slight influence on the environmental performance.

4 CONCLUSION AND OUTLOOK

The development of environmentally sound products is a worldwide priority. Especially the usage phase offers a high potential for ecological improvements, because most of the energy of active, technical products is consumed during this life cycle phase. The present paper presents a scheme to categorise and specify factors that influence the environmental impacts during the usage phase of a product or more holistically of all system elements within a socio-technical system. To support product developers in applying ecodesign and developing environmentally sound products, it needs to be identified for which products an ecological improvement will result in a greater saving of resources and energy or in other words, which products have a higher ecodesign potential than others. To do so products need to be clustered according to their usage profiles. These profiles result out of an estimation of the influencing factors that could be identified within this publication. In a further research, the complex relations and dependencies of these factors must be analysed to depict more specific usage profiles. The influence of intentional or unintentional mishandling must be investigated in addition to already existing approaches. To gain information about possible and typical usage or task problems as well as their causes, usage scenarios must be designed and evaluated (Wiese et al., 2004). Afterwards, recommendations to support product developers in applying ecodesign and with that to develop environmentally sound products can be derived.

REFERENCES

Abele, E.; Anderl, R.; Birkhofer, H.; Rüttinger, B. (Hg.) (2008), *EcoDesign. von der Theorie in die Praxis*. Berlin, Heidelberg: Springer-Verlag. ISBN 978-3-540-75438-1

Bhamra, T. A. (2004), "Ecodesign: the search for new strategies in product development", In: *J. Engineering Manufacture* (218), S. 557–569. DOI: 10.1177/095440540421800509

Blessing, L. T. M.; Chakrabarti, A. (2009), *DRM, a design research methodology*. Dordrecht,, New York: Springer. ISBN 978-1-84882-587-1

Byggeth, S.; Hochschorner, E. (2006), Handling trade-offs in Ecodesign tools for sustainable product development and procurement. In: *Journal of Cleaner Production* 14 (15-16), S. 1420–1430. DOI: 10.1016/j.jclepro.2005.03.024

Dannheim, F. (1999), *Die Entwicklung umweltgerechter Produkte im Spannungsfeld von Ökologie und Ökonomie*, Fortschr.-Ber. VDI Reihe 1 Nr. 320. VDI-Verl., Düsseldorf.

Dannheim, F.; Birkhofer, H. (1998), "Die Bedeutung der Nutzungsphase für die Entwicklung umweltgerechter Produkte". In: *Konstruktion 50,* Springer, Berlin S. 27-37.

DIN CEN/TS 16524 (DIN SPEC 33925):2013-12: Mechanische Produkte - Methodik zur Verminderung der Umweltauswirkungen bei Produktgestaltung und Entwicklung.

DIN EN ISO 14050:2010-08: Umweltmanagement - Begriffe.

DIN-Fachbericht ISO/TR 14062:2002: Umweltmanagement - Integration von Umweltaspekten in Produktdesign und -entwicklung.

Ehrlenspiel, K.; Meerkamm, H. (2013), *Integrierte Produktentwicklung. Denkabläufe, Methodeneinsatz, Zusammenarbeit*. 5., überarb. und erw. Aufl. München: Hanser. ISBN: 978-3-446-43548-3

European Commission (26.01.2011), Mitteilung der Kommission an das Europäische Parlament, den Rat, den Europäischen Wirtschafts- und Sozialausschuss und den Ausschuss der Regionen. *Ressourcenschonendes Europa - eine Leitinitiative innerhalb der Strategie Europa 2020,* European Commission, Brussels.

Feldhusen, J.; Grote, K.-H. (2013), *Pahl/Beitz Konstruktionslehre. Methoden und Anwendung erfolgreicher Produktentwicklung*. 8., vollst. überarb. Aufl. 2013. Berlin, Heidelberg: Imprint: Springer Vieweg.

Geppert, J.; Stamminger, R. (2010), "Do consumers act in a sustainable way using their refrigerator? The influence of consumer real life behaviour on the energy consumption of cooling appliances", In: *International Journal of Consumer Studies* 34 (2), S. 219–227. DOI: 10.1111/j.1470-6431.2009.00837.x

Grießhammer, R.; Buchert, M.; Gensch, C.-O.; Hochfeld, C.; Manhart, A.; Reisch, L.; Rüdenauer, I. (2007), *PROSA – Product Sustainability Assessment*. Leitfaden. Öko-Institut e.V., Institut für angewandte Ökologie. Freiburg.

Grüner, C. (2001), *Die strategiebasierte Entwicklung umweltgerechter Produkte,* Fortschr.-Ber. VDI Reihe 1 Nr. 349. VDI-Verl., Düsseldorf.

Hanusch, D. (2011), *Die Entwicklung nachhaltiger Produkte - Theoretischer Anspruch und Möglichkeiten zur praktischen Umsetzung in der sozialen Dimension*. Fortschr.-Ber. VDI Reihe 1 Nr. 413. VDI-Verl., Düsseldorf. ISBN 9783183413010

Hubka, V. (1984), *Theorie technischer Systeme: Grundlagen einer wissenschaftlichen Konstruktionslehre* Springer, Berlin. ISBN 978-3-540-12953-0

ISO 20282-1:2008-10: Einfachheit der Handhabung von Produkten des täglichen Gebrauchs - Teil 1: Gestaltungsanforderungen im Kontext von Anwendungs- und Benutzermerkmalen.

Johansson, G. (2002), "Success factors for integration of ecodesign in product development", *Environmental Management and Health,* Vol. 13 (1), S. 98–107. DOI: 10.1108/09566160210417868

Lasser, M. (2002), *Problemmöglichkeits- und -einflußanalyse - Ein Verfahren zur Vorausbestimmung von Schwachstellen in Nutzer-Produkt-Systemen*. Shaker Verlag, Aachen. ISBN 3-8322-0506-3

Ma, Jian; Yin, Fengfu; Liu, Zhenyu; Zhou, Xiaodong (2012), The Eco-design and Green Manufacturing of a Refrigerator. In: *Procedia Environmental Sciences* 16, S. 522–529. DOI: 10.1016/j.proenv.2012.10.072

Oberender, C. (2006), *Die Nutzungsphase und ihre Bedeutung für die Entwicklung umweltgerechter Produkte*, Fortschr.-Ber. VDI Reihe 1 Nr. 385. VDI-Verl., Düsseldorf. ISBN 3-18-338501-5

Pahl, G.; Beitz, W.; Feldhusen, J.; Grote, K.H. (2007), *Engineering Desing - A systematic Approach*.3rd Edition. Springer-Verlag London Limited. ISBN 978-1-84628-319-2

Pigosso, D. C.A.; McAloone, T. C.; Rozenfeld, H. (2015), "Characterization of the State-of-the-art and Identification of Main Trends for Ecodesign Tools and Methods: Classifying Three Decades of Research and Implementation". In: *Journal of the Indian Institute of Science* 94, Nr. 4, S. 405–427. ISSN: 0970-4140 Coden-JIISA.

Popoff, A.; Millet, D.; Pialot, O. (2016), A method for identifying and quantifying Usage EcoDrifts. In: *Journal of Cleaner Production* 137, S. 527–536. DOI: 10.1016/j.jclepro.2016.07.122

Rossi, M.; Germani, M.; Zamagni, A. (2016), "Review of ecodesign methods and tools. Barriers and strategies for an effective implementation in industrial companies". In: *Journal of Cleaner Production* 129, S. 361–373. DOI: 10.1016/j.jclepro.2016.04.051

Ruedenauer, I (2006), *Kuehl- und Gefriergeräte als EcoTopTen-Produkte*. Produkt-Nachhaltigkeitsanalyse (PROSA) von Kuehl- und Gefriergeräten und Ableitung von Kriterien fuer die EcoTopTen-Verbraucherinformationskampagne. Öko-Institut e.V., Freiburg.

Schlacke, S.; Alt, M.; Tonner, K.; Gawel, E.; Bretschneider, W. (2015), *Stärkung eines nachhaltigen Konsums im Bereich Produktnutzung durch Anpassungen im Zivil- und öffentlichen Recht*. Texte 72/2015. Umweltbundesamt, Dessau-Roßlau.

Schott, H. (1998), *Informationsressourcen und Informationsmanagement für die Entwicklung umweltgerechter Produkte.* Fortschrittberichte VDI Reihe 1, Nr. 297. VDI Verlag, Düsseldorf.

Serna-Mansoux, L.; Domingo, L.; Millet, D.; Brissaud, D. (2014), A Tool for Detailed Analysis and Ecological Assessment of the Use Phase. In: *Procedia CIRP* 15, S. 502–507. DOI: 10.1016/j.procir.2014.06.059

The European Parliament and of the Council of the European Union (2009): *Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products.*

Tukker, Arnold (2004), *Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet.* In: Bus. Strat. Env. 13 (4), S. 246–260. DOI: 10.1002/bse.414

Weber, C.; Steinbach, M.; Botta, C.; Deubel, T. (2004), "Modelling of product-service systems (PSS) based on the PDD approach" *International Design Conference - DESIGN 2004*. May 18-21, Dubrovnik.

Wiese, B.; Sauer, J.; Rüttinger, B. (2004), Umweltgerechte Produktentwicklung: Konzepte, Befunde und Perspektiven eines interdisziplinären Forschungsprojektes. In: *Umweltpsychologie* 5 (1), S. 52–68.

Zhao, S.; Birkhofer, H.; Bohn, A. (2011), "The concept of ecological levers - a pragmatic approach for the elicitation of ecological requirements", *International Conference on Engineering Design, ICED2011*, 15-18. Aug. Copenhagen, S. 302-311.