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LIFE CYCLE-BASED CLASSIFICATION AS A SIMPLIFIED APPROACH FOR IMPROVING THE ENVIRONMENTAL IMPACT OF PRODUCTS

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Abstract: The present article touches upon the topic of LCA simplifications within the scope of data inventory for the purposes of life cycle analysis of selected products. The paper's main objective was to define the features of products for which the calculation of the simplified environmental indicators may be recommended. The selected products differed in many aspects, and they could be generally classified into two separate groups: *active* products, which require energy to fulfil their function, and *passive* products, which do not need an energy supply. On the basis of the presented *active* products, it has been established that the key issue during their classification should be mass per unit and operational mode. The features of the analysed *active use-intensive* products include: low mass per unit, relatively short life cycle related to intensive use, possibility for fulfilment of functions without additional material flows and operation with constant AC power supply. A simplified LCA should be recommended at the first stage of project planning, when there are many versions/conceptions of a given product and when a full LCA is virtually impossible. In light of the above-mentioned, simplified environmental indicators would be the first filter for the versions of a new product being considered. Thanks to the proposed approach, the designer is able to categorise the tested product and will be aware of any potential critical points of its life cycle (hot spots).

Keywords: Life Cycle Assessment, simplified inventory model, environmental classification of products, cut-off error.

1. Introduction

The concept of Life Cycle Management (LCM) serves as an example of bringing life cycle thinking to businesses in the specific fields of organisation and product and service management to ensure a proper balancing of production and consumption. Environmental Life Cycle Assessment (LCA) is one of the pillars of LCM. According to the ISO Standard, LCA involves "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040, 2009) and is an analytical tool that can be applied in many areas of environmental management, for example in eco-design (Baran, and Janik, 2013; Baran, Janik, and Ryszko, 2014). Numerous initiatives related to promoting LCA in the economic area have been launched over the last several years. They can be observed as a part of the more and more intensive activity made by various institutions (legislative, consulting, research, scientific) for the sake of supporting entrepreneurs in the application of LCA methodology in business (Ritzén et al., 1996; Rubik, and Frankl, 2000; "LCA to go", 2010; Agarwal et al., 2012; Kronenberg, and Bergier, 2012; Kurczewski, 2014). LCA can be also applied for promotion of more sustainable supply chains (Burchart-Korol, 2012; Burchart-Korol, Czaplicka-Kolarz, and Kruczek, 2012; Mesaric, Šebalj, and Franjkovic, 2016) and even in lifestyles (Matuštík, and Kočí, 2019).

Many factors which potentially determine the growing need for LCA may be enumerated upon, in particular, the European Commission initiative on establishing and using common methods to measure and communicate the life cycle environmental performance of products and organisations (Recommendation 2013/179/EU). In contrast to carbon or water footprints, which are single issue-oriented factors, an environmental footprint is a multi-indicator measure that includes 16 impact categories (Recommendation 2013/179/EU). The remaining stimulants of taking account of the environmental aspects of life cycle in an organisation's activity (as well as during product design and product development) include tendencies towards green public tenders, which generate demand for environment-friendly products (European Commission, 2011), as well as formalised stimuli – green requirements with regard to energy-related products (Directive of the European Parliament and of the Council 2009/125/EC of 21 October 2009) and construction (Regulation (EU) No. 305/2011 of the European Parliament and of the Council of 9 March 2011). Changes within the scope of ISO 14001 requirements may also be extremely significant, as enterprises with implemented environmental management systems will be increasingly motivated to analyse the environmental impact of the life cycle of their products and services (Lewandowska, and Matuszak-Flejszman, 2014).

However, in literature (Van Hemel, and Cramer, 2002; Masoni, Scimia, and Raggi, 2004; Le Pochat, Bertoluci, and Froelich, 2007; Chevalier, 2009; Arana-Landin and Heras-Saizarbitoria, 2011; Buttol et. al., 2012), it is emphasised that LCA may be considered an overly complicated eco-design tool for business practice. Despite the fact that the aforementioned research focuses mainly on small and medium-sized enterprises (SMEs), their core conclusions seem to be universal. Full LCAs tend to be costly, time-consuming and difficult to realise, in particular, if the analysis is carried out by people without proper experience. Hence, the application of qualitative approaches based on a simplified LCA appears to be a worthy solution, and the simplifications relate to the life cycle inventory or/and a life cycle impact assessment (Sun, 2004 after: Hanssen, 1997; Todd, and Curran, 1999; Soriano, 2004; Sousa, and Wallace, 2006; Okrasinski et al., 2011; Pamminger et al., 2013). The present paper is focused on determining the simplified LCA indicators based on the environmental classification of products. It is still an important part of the discussion about LCA methodology and applicability.

There are numerous approaches described in the literature on product classification depending on the assumed criteria, including environmental impact (Sun, 2004 after: Hanssen 1997; Akermark, 1999; Soriano, 2004; Wimmer, Zust, and Lee, 2004; Sousa and Wallace, 2006; Joachimiak-Lechman et al., 2017). The approaches differ significantly, and, in some sense, they contradict one another. Namely, different authors put the same products in different classes. Consequently, the identified environmental hot spots, eco-design strategies and developmental recommendations for the same products diverge.

A relatively simple classification consists in the division of products into *active* products, if an energy supply is the condition of function realisation, and *passive* products, which do not need to meet this condition (Sun, 2004 after: Akermark, 1999), and leads to the observation that the environmental impact of *passive* products is caused by the production of a given material, and the major environmental impact of *active* products is attributed to using them. Therefore, it was recommended to determine the Material-based Environmental Performance Indicator (I_M) for *passive* products and the Energy-based Environmental Performance Indicator (I_E) for *active* products (Soriano, 2004; Sun, 2004). However, the presence of products which are not characterised by a dominant stage of life cycle should be noticed. These products could be described as *combined products*, and they should be considered in relation to both *active* and *passive* products. In the case of *combined products,* calculating I_M or I_E exclusively is potentially beyond the acceptable risk. Therefore, in this context, it is recommended to determine the total Environmental Performance Indicator (I) that can be calculated in the following way: I_M+I_E (Soriano, 2004; Sun, 2004).

In the present paper, emphasis was placed on *active* products, as its main objective is to define the features of these products. The appropriateness level of the simplifications of the inventory model, including potentially most significant issues in the life cycle of the analysed products – whether and to what extent they allow for recording information about environmental impact, has been verified. The possibility of the application of the postulated simplifications has also been discussed. The problem of determining the simplified LCA indicators for selected products has been touched upon in literature (e.g. Soriano, 2001; Sun, 2004). From this perspective, the research presented in the paper amounts to a continuation of previously conducted analyses; however, it is visibly centred on correlating the environmental impact information of *active* products with their most significant features of the analysed products.

2. I_M and I_E – between EPIs and life cycle environmental performance

The proposed concept of I_M and I_E indicators combines approaches relevant both for environmental performance indicators (EPIs) used in organisation-oriented environmental management systems (EMS) and life cycle tools based on the recommendations of ISO 14040s (LCA, PEF/OEF, Ecodesign Pilot). From the first point of view, the I_M and I_E indicators can be considered as a measure of saving materials and energy (I_M = consumption of materials, expressed in mass units; I_E = energy consumption, expressed in energy units). A certain analogy to environmental performance indicators, determined by ISO 14031:2013 as Operational Performance Indicators (OPIs) (e.g. Total Material Input, Total Water Input) (https://www.env.go.jp/policy/j-hiroba/PRG) or similar measures used in the EMAS programme (e.g. Material efficiency, Water, Energy Efficiency), can be observed in them.

Environmental performance indicators mean “a specific expression that allows measurement of an organisation’s environmental performance” (Regulation (EC) No. 1221/2009 of the European Parliament and of the Council). Each core indicator is composed of a figure: R displays the ratio A/B, whereas figure A indicates the total annual input/impact in the given field, and figure B indicates the overall annual output of the organisation. Figure B may be seen as the total annual gross value added or overall annual output expressed in tonnes or, in the case of small organisations, as the total annual turnover or number of employees. Thus, in EMS practice, the energy efficiency indicator of environmental performance juxtaposes, for example, the energy intensity of the organisation’s processes with the volume of its production.

Such calculation of EPI follows from the definition of environmental performance used in EMS, which is understood as “measurable results of an organisation’s management of its environmental aspects” (Regulation (EC) No. 1221/2009 of the European Parliament and of the Council) and “performance related to the management of environmental aspects” (ISO 14001, 2015). In both definitions, environmental performance is considered through the prism of environmental aspects, which indicates its inventory character. Moreover, EPI indicators do not take into account the life cycle perspective and are limited only to inputs and outputs (environmental aspects) measured within the boundaries of a given organisation (direct aspects). Thus, although the one-dimensionality (material- or energy-orientation) and inventory character point to the similarity of the I_M and I_E parameters to EPIs, there are major differences between them. The I_M and I_E indicators were proposed based on life cycle analysis. They relate to two independent stages of the life cycle (and therefore extend beyond the boundaries of the organisation itself), and their values are related to the functional unit defined from the point of view of the entire life cycle. Moreover, they take into account not only direct environmental aspects but also supply chain activities. Each input of material (I_M) or energy (I_E) from the technosphere is analysed “from cradle to gate”, which is possible thanks to the intensive development of inventory databases (e.g. ELCD database, Ecoinvent, GaBi database).

After calculating the value of the I_M or I_E indicator (inventory result), it will be subjected to Life Cycle Impact Assessment, which allows for obtaining information about the potential impact on the environment. Thus, from this point of view, it can be considered that the I_M and I_E indicators show similarities to LCA or environmental trace analyses, which constitute the measures of the “life cycle environmental performance”. As opposed to the definition of EPIs, the definition of environmental performance in the life cycle includes a clear reference to the life cycle and goes as follows: “quantified measurement of the potential environmental performance taking all relevant life cycle stages of a product or organisation into account, from a supply chain perspective” (European Commission, 2013). The key features of life cycle environmental performance are: inclusion of life cycle perspectives, quantitative measurements, focus on (potential) environmental impacts and the possibility of referring both to products and the organisation. In the above definitions, redirecting attention from environmental aspects to (potential) environmental impacts implies differences in the approach to understanding and quantifying environmental performance. A much more advanced inventory of environmental aspects (including not only direct aspects but also the identification of aspects in upstream and downstream processes), as well as the use of multiple indicators of potential environmental impact as an assessment criterion, are significant for measuring life cycle environmental performance.

In conclusion, the proposed simplified indicators of I_M and I_E life cycle compile the environmental harmfulness of a certain aspect of the product life cycle, material consumption of production and energy intensity of use in relation to the functional unit, respectively, which, according to the definition, is “quantified performance of a product system for use as a reference unit” (ISO 14040, 2009). Therefore, it is an approach that links inventory information which relates to specific product functionality to environmental impact. These indicators can thus be used within the framework of environmental reporting, especially since, according to the EMAS Regulation, companies can offer additional indicators to assess the effectiveness of environmental performance, and it is even better when they extend beyond the boundaries of the organisation and relate to the life cycle perspective.

3. Materials and methods

The presented study included 30 products of various functionality, mass, material composition, durability and use intensity. Such a selection was deliberate and motivated mainly by the willingness to compare products belonging to different product categories. In several cases, the research embraced products of similar features; however, it aims at establishing whether a simplified LCA is justified independently of certain features – type of material and durability (office furniture), type of material and form of final disposal (laminates) and energy demand (lighting systems, bar furniture).

The paper presented examples of products for which data was collected within own research or borrowed from previously published LCA case studies. Product-specific data coming directly from producers was gathered for over 43% of products (for almost all *passive* products and for five *active* products). In all cases, the secondary inventory data was reviewed and updated (if necessary).

The LCA studies were conducted with the use of the Impact 2002+ LCIA method (Jolliet et al., 2003). In all cases, the boundaries of the studies included production stage, use (including transport to a consumer) and final disposal of waste. Final disposal scenarios were based on the legal requirements for waste management in Poland (i.e. levels of collection and recycling of packaging, used electrical and electronic equipment, etc.). The products presented in the article have different functions, and thus one common functional unit has not been identified. Each time, however, this was defined for the use stage (taking into account the viability), and most often the reference flow was a single product.

In order to determine to what extent and whether the application of the simplified inventory model will allow for achieving satisfactory results of the environmental analysis (in the context of the preselected products), the comprehensive and simplified LCA results were compared. The comprehensive LCA studies included inventory data relating to all life cycle stages and was verified by the mass-energy balance. The simplified LCA studies included inventory data relating only to selected processes/elements – energy consumption of use stage (*active* products) and material consumption of production (*passive* products).

A sensitivity analysis was evaluated for checking the change in the final scores resulting from the simplification of the inventory model. Having received the LCA indicator representing the comprehensive study, a simplified LCA was conducted and new environmental indicators were obtained for each product: I_M for *passive* products and I_E for *active* products. Next, the cut-off error (a truncation error) was defined by calculating the percentage difference between the initial value of the analysed life cycle indicator and the value of this indicator obtained as a result of the simplified life cycle inventory. The total Environmental Performance Indicator, i.e. the Integrated Indicator I_I, was defined for the *active* products, for which the calculated cut-off error was too high. This indicator embraces both the material consumption of production and the energy consumption of use.

The verification of recommended solutions was made on the basis of the cut-off error value, for which the contribution analysis and ranking criteria recommended by the PN-EN ISO 14044: 2009 standard were used:

- +/- 10% – confirms a very good adjustment of simplifications and omission of low-impact environmental aspects,
- between +/10% and +/- 25% – indicates an acceptable adjustment of simplifications and omission of aspects with a certain environmental impact,
- above +/- 25% – indicates the exclusion of significant and/or the most significant environmental aspects from the inventory model, which results in obtaining an LCA indicator failing to reflect the life cycle impact in a credible manner.

According to the interpretation presented in this standard, the environmental aspect is considered significant if its share in the total impact is over 25%. Accordingly, if after limiting the scope of the LCA study a result which accounts for 75% (or less) of the full LCA result is obtained, this means that significant environmental aspects were omitted from the inventory model.

4. Results

4.1. Results of the Simplified LCA – *passive* products

Figure 1 presents the percentage LCA results received for the production systems defined in the comprehensive LCA studied (the black bar), which has been considered to be 100%, as well as simplified LCA results obtained by taking into account the production of product components only (the grey bar). The difference in the bars' height reflects the difference in the LCA results obtained in two versions (comprehensive and simplified). Moreover, it illustrates the cut-off error characteristic of the *passive* products.

In the case of several of the analysed *passive* products, a relatively high cut-off error (above 25%) was observed, which is illustrated by the white line in Figure 1. This means that the omitted environmental aspects have a relatively significant impact; therefore, the omission of them in the inventory model may be considered risky. This group includes: outerwear, a reusable towel, disposable unit packaging (laminated bags). This set of products can be described as *passive combined*. The first two examples are products which are physically improper for power supply or any other utility as the construction condition of performing a given function. However, the traditionally accepted manner of realising their functions calls for additional materials which may include the energy. These materials can be described as “accompanying environmental interventions”, and they are linked here with the activity of washing. The significance of associated environmental interventions in the life cycle of a *passive* product is determined by the product’s mass, durability and use intensity. The above-mentioned products are characterised by a relatively low mass per unit (up to 2 kg), whereas the length of their life cycle is inextricably connected with the frequency of use. In accordance with the research assumptions, the durability of a cotton towel, which is often washed, is only two years, whereas the durability of outerwear (a fleece jacket) is, on average, five years (washed only twice a year). Due to the above-mentioned issues, exclusively establishing the I_M Indicator for these products does not allow for obtaining ample information on their life cycle impact. Similar observations can be made in relation to packaging made of laminates. Packaging plays an important role in trade. The distribution of the packaged product is of such importance that omission of this process from the life cycle assessment of packaging is risky.

In the case of the remaining passive products subjected to analysis, a simplified LCA consisting in establishing the I_M Indicator should be considered justified. This set of products may be described as *passive production-intensive*. In general, *passive* products, for which a satisfactory level of preserved LCA results has been observed, are characterised by a relatively high mass per unit and long useful life. Even if additional material or energy streams occurred at the stage of the use of the analysed products, their potential impact is insignificant, as a relatively high mass causes a visible shift of the total life cycle impact towards the production stage – in such a case, it is justified to establish the I_M Indicator exclusively.

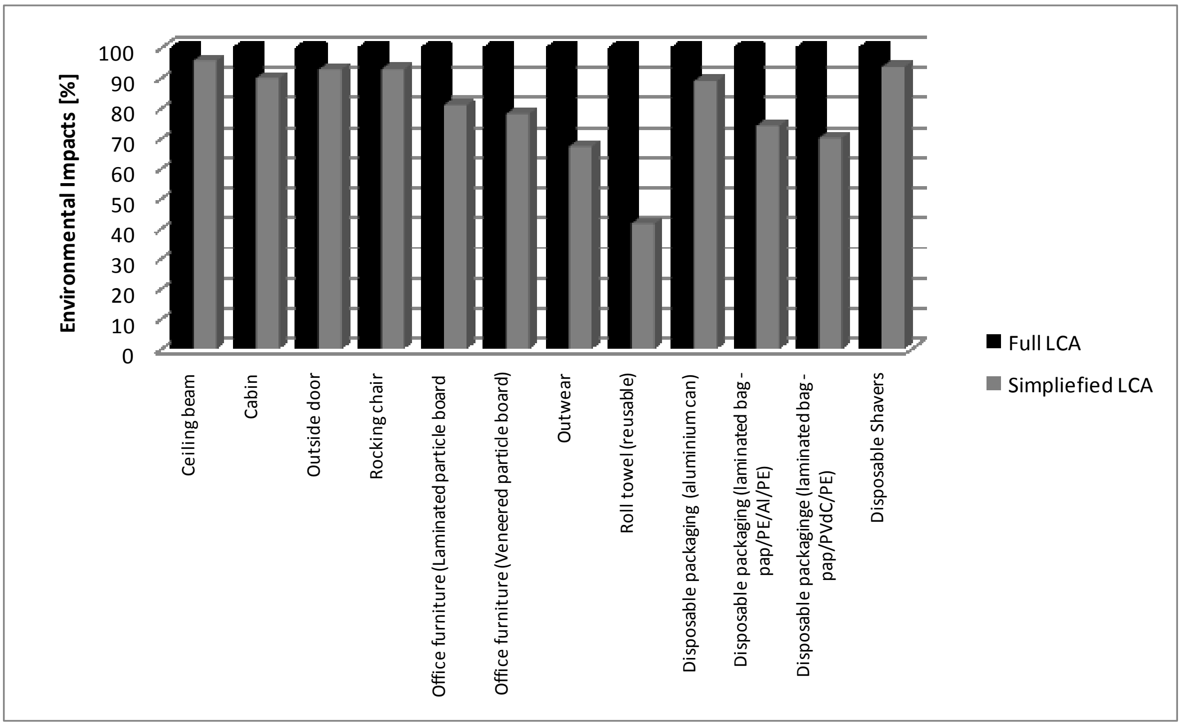

Figure 1. Cut-off error levels observed as a result of simplification of the life cycle inventory – *passive* products. Source: own elaboration based on: Joachimiak-Lechman, 2016.

4.2. Results of the Simplified LCA – *active* products

Table 1 shows the cut-off levels of the LCA results of selected *active* products, which were caused by limiting the scope of the study only to energy consumption during the use stage (Column 3). In some relevant cases for which obtained cut-off error was too high, the I_I Indicator had also been defined. The proposed simplifications are recommended for application in the area of eco-design (the initial stage) if the cut-off error amounts to 25% or less.

Table 1.
Differences in LCA results (cut-off error) obtained for the comprehensive and simplified life cycle inventory – active products

Lp.	Product	Cut-off error Simplified LCA - I_E Indicator	Interpretation	Cut-off error Simplified LCA - I_I Indicator	Interpretation
		[%]	Recommended/ Not Recommended	[%]	Recommended/ Not Recommended
1.	Bar furniture	33.07	NR	0.79	R
2.	Bar furniture (with lower energy consumption)	42.00	NR	1.56	R
3.	Coffee machine	8.20	R	-	-
4.	Electric hand dryer	3.64	R	-	-
5.	Electric kettle	0.97	R	-	-
6.	Electric toothbrush	29.49	NR	0.64	R
7.	Electric oven	20.99	R	-	-
8.	Desktop PC	31.81	NR	4.54	R
9.	Dishwasher	27.69	NR	11.54	R
10.	Fridge-freezer	20.32	NR	-	R
11.	Laptop	38.89	NR	5.55	R
12.	Lighting system (fluorescent lamp)	2.67	R	-	-
13.	Lighting system (LED)	1.40	R	-	-
14.	Microwave	31.58	NR	10.53	R
15.	Toaster	10.34	R	-	-
16.	TV set	62.5	NR	4.00	R
17.	Washing machine	32.68	NR	18.13	R
18.	Vacuum Cleaner	14.00	R	-	-

Source: own elaboration based on: Joachimiak-Lechman, 2016.

During the analysis of *active* products, it was observed that a low level of the cut-off error is characteristic of products with a relatively low mass per unit (up to 6 kg) which do not require (or require to an insignificant extent) additional materials (a kettle, a toaster, a hand dryer, lighting systems, as well as a coffee machine and a vacuum cleaner). Moreover, in relation to these products, high use intensity was assumed. This fact has been reflected in their relatively short life cycle (up to 5 years, except the vacuum cleaner – up to 10 years). Their vulnerability to repair was also defined – the replacement of broken/worn elements is both difficult and economically viable. These products have been called *active use-intensive*. Relatively heavy products amount to an interesting example of these as their operation specificity – cyclical activity (a refrigerator with a freezer) and intense use scenario (an electrical oven) – leads to their belonging to this group.

In the case of some of the analysed products, the simplification of the life cycle inventory leading to the calculation of the I_E Indicator, which is typical for *active* products, caused the omission of the aspects amounting to more than 25% of the comprehensive LCA indicator (Table 1 – Column 3). This group of products has been named *active combined*, and in their case, the Integrated Indicator I_I has been determined. The I_I Indicator consists in the integration of I_M and I_E Indicators. A simplified life cycle inventory of *active combined* products, therefore, includes the material consumption of production and the energy consumption of the use stage.

As has been noted, in the case of 6 out of 8 products for which the I_I Indicator was calculated, the simplified life cycle analysis resulted in the omission of low-impact environmental aspects (cut-off error below 10%; Table 1 - Column 4). In relation, the highest cut-off error was observed for a washing machine and a dishwasher (18.3% and 11.54%), which stems from the fact that their use is related not only to the energy supply, but also to the supply of additional materials (water, detergents, etc.) However, as a result of the conducted research, it has been concluded that, in the context of *active combined* products, the recommended inventory model simplifications do not cause an elimination of the important environmental issues from the LCA analysis.

A significant conclusion of the research is that the *active combined* products could be grouped in a certain way. The first group comprises notably different products as *active use-intensive*, as they might be characterised by a relatively high mass per unit (approx. 50 kg). Moreover, they need to be provided with additional materials which support the realisation of their functions (a washing machine, a dishwasher). The next group consists of products which appear to be totally unlike the first group. These products are relatively light (up to 5 kg), they are intensely used and are independent of providing additional materials (apart from electricity). This makes them similar to *active use-intensive* products. What distinguishes these products from *active use-intensive* products is the operation due to the cyclical charging of a battery (a laptop, a toothbrush). The last of the distinguished groups consists of products which have a medium mass per unit (above 10 kg) and do not require any additional material to fulfil their function. Their use intensity varies (high – a PC, a TV; or relatively lower – a microwave). Therefore, they are, in some aspects, similar to *active use-intensive* products, but their higher mass excludes the I_E Indicator as a recommended simplified environmental indicator.

5. Discussion

It is ought to be emphasised that a simplified LCA will not replace a comprehensive version of the analysis and entails a certain amount of risk of distorting environmental communication. On the other hand, a comprehensive LCA study requires gathering a large quantity of specific data. Therefore, a simplified LCA should be mainly recommended at the first stage of project planning, when there are many versions/conceptions of a given product and when a full LCA is virtually impossible. In light of the above-mentioned, simplified environmental indicators would be the first filter for the versions of a new product being considered. A comparative LCA, as the simplified inventory models, seem to be best fitted for it, and they should always relate to functionally balanced products. If we assume that they belong to the same product category, the definition of simplified indicators for them – I_M Indicator, I_E Indicator or Integrated Indicator – will potentially contribute to a similar value of the cut-off error. However, it should be taken into account that the introduction of revolutionary innovations, e.g. the extreme reduction of energy consumption, may cause a shift of the environmental burden towards production. Furthermore, despite the fact that in the case of the base version of a product, which is *active use-intensive*, the calculation of the I_E Indicator was justified; the same procedure for the improved version of the product, which also belongs to the *active intensive-use* group, would involve a great deal of risk. On the one hand, it contradicts the validity of the proposed simplifications; on the other hand, it proves that each eco-design situation and the application of a simplified LCA in eco-design should be thoroughly considered.

In the context of the results obtained in the research, the following issues should be stressed:

- The division of products according to the necessity to provide energy as the crucial condition of the realization of their functions is rather unequivocal; however, it only allows for distinguishing two large groups of products, including varied objects, which need further divisions. Despite the fact that in the case of *active* products, the classification into *active use-intensive* and *active combined* appears to be satisfactory, the group of *passive* products calls for more subgroups.
- In the case of *active* products, the direct electricity consumption is possibly always significant enough to justify the definition of the I_E Indicator (as a single indicator in the case of *active use-intensive* products or as a link with I_M in the case of *active combined* products) within a simplified LCA. However, determining only the I_M Indicator for *passive* products, whose dominant impact of the production stage (above 90% - *passive production-intensive*) is very characteristic, may be risky. Similarly, determining this indicator in the context of the *passive combined* group is doubtful. A relevant example here seems to be a piece of office furniture made of particle board coated with veneer. This is a typically passive product with a considerable contribution of the production stage in the total environmental impact of the life cycle. An exclusive calculation of the

I_M Indicator may cause that the cut-off error would reach a relatively high value close to the acceptability level. This is related to the production materials involved, as their environmental harmfulness is so insignificant that it contributes to an increase in the importance of production processes accompanied by energy consumption. Hence, the following question arises: should not the division of *passive production-intensive* products be much more detailed and take account of the allocation of environmental impact at the product stage considered in isolation? Moreover, it is even more justified to classify *passive combined* products in a more precise and detailed way. Resource consumption during usage is characteristic of these products, but its significance depends on numerous issues; therefore, in the context of these objects, a simplified inventory model would be difficult to apply.

- The above-mentioned issues lead to the conclusion that the simplifications of the inventory models, consisting in reducing the scope of analysis, should be recommended mainly for *active* products. Moreover, the simplifications ought to come down to the question of the energy consumption of use and (optionally) the material consumption of production. Three aspects are pivotal while grouping *active* products: mass per unit, operational mode (with a constant power supply or through charging a battery) and use intensity. The first two parameters are, to a large extent, obvious for the designer; hence, they should be able to easily select the appropriate LCA simplification (I_E or I_I). The problem of predicting use intensity in relation to specific products is more complex because of the use scenario, as it mainly depends on the buyers' behaviour. However, it should be assumed that the decrease of the intensity of use of *active use-intensive* products, which can be characterised by the features typical of this group (low or moderate mass per unit, a relatively short life cycle), will potentially lengthen their durability, and, consequently, they will remain in this product group. Due to the fact that the issue of the intensity of product use is ambiguous, it should also be assumed that products with a large mass per unit, which predetermines their belonging to the *active combined* group, ought to be classified in this way independently of the expected (in accordance with traditional practices) use intensity.

6. Summary

Determining particular elements of the life cycle (environmental hot spots), which generate a considerable environmental impact for each group/subgroup of products, is the basis for formulating the inventory model simplifications. The division of products into *active* and *passive* is unambiguous. A designer who will use such a general classification, after defining the product's features, should select the version of the simplified LCA – through determining the Energy-based Environmental Performance Indicator exclusively or in combination with the Material-based Environmental Performance Indicator. In order to determine the I_M Indicator, a designer analyses the so-called Bill of Materials and defines the mass of individual elements. In most cases, the data is easily accessible and relatively reliable. In the case of an LCA study based on the I_E Indicator, the inventory model includes the total energy amount of energy consumed during a given product's use, which is calculated on the basis of the number of hours in operation (assumed in the use scenario and the designed durability) and power rating.

The application of simplified inventory models aims to reduce the time consumption and effort of LCA related to gathering and allocating data, as well as typing the data into the calculating program. However, the scope reduction of the analysis must not notably affect the results, because this would be burdened with the risk of distorting environmental communication. In addition, it would trigger a situation in which the designer attempts to improve the environmental aspects of the life cycle that do not pose major environmental threats. In the course of the present research, it has been proven that:

- a simplified LCA based on the I_E Indicator is appropriate in the case of the analysed products described as *active use-intensive*, i.e. the products with the dominant role of the stage of use within their life cycle,
- determining the I_E Indicator for *active* products whose environmental performance is distributed over two or more stages (production and use) – *active combined* – causes unacceptable distortion of the LCA results,
- in the case of *active combined* products, the proposed approach to a simplified LCA consisting in limiting the scope of the life cycle analysis to electricity consumption during their usage and material consumption in production is justified.

On the basis of the conducted research, the distinguishing features of *active use-intensive* and *active combined* products have been defined. The following characteristics are typical of the analysed *active use-intensive* products: low mass per unit, relatively short life cycle, ability to realise functions without additional material streams and operation with a constant AC power supply. Moreover, these products are intensely used and susceptible to repair/replacement of worn parts. The analysed *active combined* products have a higher mass and longer life cycle, and some of them require the supply of additional materials. It is important that, despite the fact that *active combined* products may also be light and of a short life cycle, they are different than *active use-intensive* products, as they do not need a constant power supply. Therefore, on the example of the presented products, it has been concluded that the key aspects of classifying *active* products should be mass per unit and operational mode. The relatively large mass per unit of the *active* products shifts environmental burdens towards the stage of production and results in them belonging to the *active combined* group. The ability of the *active* products to operate without a power supply may contribute to similar observations.

Thanks to the proposed approach, the designer is able to categorise the tested product and will be aware of potential critical points of its life cycle (hot spots). On this basis, it will also be possible to build an inventory model that includes data on electricity consumption at the stage of use of the product (in case of *active use-intensive* product) or contains the above-mentioned issues together with the use of construction materials (in case of *active combined* product). In an appropriate case, such an analysis will be much simpler (it will be based on key aspects of the life cycle) and, at the same time, will allow one to preserve the most important information about the environmental impacts of the analysed products.

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