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HARMONIZED INTERNET SYSTEM FOR LIFE CYCLE ASSESSMENT: EXPERT SYSTEMS APPROACH

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Abstract

The extent of the application of life cycle assessment (LCA) is not sufficient for the alternatives assessments performed in the industry in general and for the ecolabelling of the products/services. Given that the LCA is a widely-accepted methodology, the driving question behind this study was: "Is it possible to ecolabel each existing product/service in a case specific manner by using LCA results, so that the consumers would be able to know the extensive environmental impact of their decisions?". The literature has been searched for listing the main problems preventing the widespread application of LCA in ecolabelling and alternatives assessment. A system has been developed within the constraints (e.g. human resources, etc.) encountered in the literature. The resulting system is a form of an expert system, with a harmonized inter-company scope, that can perform a full LCA to be used in alternatives assessment decisions and in ecolabelling. Proposed system reduces the work load per case, establishes a well-defined scope, prioritizes case specific data, circumvents the issue of 'company secret' and enables wider application of LCA for environmental impact optimization. Another novelty is that the system considers the changes in the downstream of the supply chain due to a decision in the upstream. To establish this, the concept of 'combined total functional demand' has been introduced, which can also help in improving allocation and multifunctional product issues for end products.

Keywords: alternatives assessment, ecolabelling, expert systems, life cycle assessment, life cycle inventory

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1. Introduction

Life cycle assessment (LCA) is being used for many purposes such as ecolabelling, product improvement and product comparison in terms of environmental impact (Borghi, 2013; ILCD, 2010; Lehtinen et al., 2011). As the state of the art, the implementation of LCA has been standardized to some degree with the development of ISO 14040/44 standards and subsequent publication of guidance such as the International Reference Life Cycle Data System (ILCD) handbooks (ILCD, 2010).

Nevertheless, many problems exist in almost each step of the LCA application that are waiting to be resolved. The issues that are in interest of this study

are: the resource intensiveness of LCA studies (Iraldo et al., 2015) conducted for ecolabelling and alternatives assessment purposes, insufficient ecolabelling practices (EC, 2016) as a consequence, and the shortcomings of the life cycle inventory (LCI) for background processes to reflect case specific data (ILCD, 2010; Reap et al., 2008).

Ignoring LCA in decision making is a major factor in recent environmental degradation. The recent regulatory system lacks incentivizing the sharing of the information, among industries and with consumers, necessary for the optimization of technosphere in terms of environmental impacts. As an example; the proximity principle for transport, although it is defined in the Europe for waste

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management (EC, 2008), is not applied to other areas that are equally responsible for the environmental impact. While the application of LCA to such transport systems other than waste transport will further inform the decision makers about what is environmentally preferable, one might stress the consequences of such a wide application of LCA on free-trade. Another example is the application of ecolabels; although there are established ecolabels such as the EU Ecolabel, the application of it is frequently voluntary and insufficient (e.g. in Lithuania there are only 101 products/services that have the EU Ecolabel) (EC, 2016).

Given that the LCA is a widely-accepted methodology, the driving question behind the developed system is: "Is it possible to ecolabel each existing product/service in a case specific manner by using LCA results, so that the consumers would be able to know the extensive environmental impact of their decisions?".

Throughout the article 'assessor' refers to a person who performs the LCA in any form, 'expert' refers to a person who has expertise in LCA studies, 'technician' refers to a person who manages the processes and has knowledge about chemicals and technologies used, but not necessarily has knowledge on LCA.

Expert systems are defined as computer programs that can emulate the decision-making ability of experts by predetermined programming and databases based on expert knowledge (Jackson, 1998). This study is the result of the efforts towards developing such a system within the known constraints encountered in the literature. The developed system has been designed to be applied for case specific (or in some cases for SMEs, semi-case specific) LCI formation, to be used in the automation of obtaining case specific impact results for ecolabelling and alternatives assessment purposes.

Quite a few studies on environmental impact assessment have focused on 'expert systems' approach in parallel with the advancements in computer science (the studies include Ahlmann et al., 1992; Hakansson, 2004; Goundar, 2013; Jazzar et al., 1998; Lein, 1989; Rachida and Samia, 2013; Say et al., 2007), and to the authors' knowledge, none of them are based on inter-company information sharing for the purpose of performing an LCA.

By taking notice that the major companies should already have their input-output and product information under a permit such as integrated pollution prevention and control (IPPC) permit (EU, 2010), a system has been proposed (harmonized internet system for the application of LCA, shortly named as HIS-LCA) to be applied to the whole industry, by using 'expert systems' approach. It is also recognized that, such a system should be implemented globally. The need for developing such a system has been further discussed and solutions have been proposed in the following sections.

2. Materials and method

The problems preventing the widespread implementation of LCA have been searched in the scientific literature, and taken as the design constraints for the proposed system. With the guidance of these constraints, technical considerations and possible solutions (obtained either from literature or by creative thinking), a system has been proposed as an overall solution.

3. Results and discussion

The constraints that have been identified in the literature are as follows:

The resource intensiveness of LCA studies found to be among the most limiting factors for the implementation of LCA (Iraldo et al., 2015; Jacobs et al., 2015; Lehtinen et al., 2011; NRC, 2014; Oguzcan et al., 2017; Reap et al., 2008). Especially, in the study by Iraldo et al., data collection from suppliers reported to be very difficult, and the financial costs of the LCA studies reported to be deterrent (Iraldo et al., 2015). Assessors preferred a financial help (such as financing, free software, consulting service made available by trade associations and tax reductions) from the authorities. However, it can be stressed that there is a scarcity in expert availability when all the products/services are concerned.

Another study by Kurczewski (Kurczewski, 2014) reports that only 3% of the SMEs in Poland use the LCA and life cycle costing (LCC) practices, mainly due to the lack of incentive, shortage of qualified personnel (LCA experts) to carry out life cycle studies, complicated methodological tools and high costs. In addition, the importance of the involvement of internal staff (especially technical staff), consultants and research institutes has been highlighted (Iraldo et al., 2015), hence the new approach must consider the involvement of these parties with keeping their availability in mind.

The most prominent motivation for companies to implement LCA studies in the future is mainly regulatory pressures (Witczak et al., 2014). Therefore, it has been recognized during the development phase of the proposed system, that the proposed system should be supported by the appropriate regulatory changes. Although the methodology proposed by Rachida and Samia (Rachida and Samia, 2013) includes LCA, the information necessary for a full LCA is unlikely to be known by a single user, therefore, without an inter-company system, local expert systems are inadequate in targeting the downstream environmental impacts. To the authors' knowledge, no inter-company system for performing LCA present in the literature.

By considering the above encountered constraints in the literature, solutions have been proposed by the authors within their best knowledge of various methods and approaches.

'Expert systems' approach has been adopted as it is known to reduce the resource and time intensiveness of many practices in many fields, including the environmental impact assessment field, as such proposals made by various authors (e.g. Ahlmann et al., 1992; Goundar, 2013; Hakansson, 2004; Jazzar et al., 1998; Lein, 1989; Rachida and Samia, 2013; Say et al., 2007). Companies have input-output and product information of their processes and products under integrated pollution prevention and control (IPPC) permit (EU, 2010). Leontief model has been used as a mathematical framework (Obikwere and Ebiefung, 2014). The rest of the solutions have been obtained by creative thinking within the given constraints.

The proposed system mainly consists of two parts: case specific inventory formation and the utilization of this data to obtain environmental impact results for ecolabelling and alternatives assessment cases. The case specific inventory formation is guided by the algorithm presented in Fig. 1. The technosphere has been divided into subcategories, separately for each product/service, for the case specific inventory formation. These categories are: 'intermediate producer', 'end producer' and 'distributor'. Here, an 'intermediate producer' is any producer that sells their defined product/service to another industrial producer. An 'end producer' is any producer that sells their defined product/service to consumers. 'Distributor' is the entity that distributes products from the 'end producer' to the consumers. If a company is an 'end producer' and a 'distributor' at the same time for a given product, it is categorized under 'end producer and distributor' for that product. This division was

necessary for scope definition along the production chain, and for the definition of the functional unit for a given end product/service. In the proposed system, the functional unit is defined for the end products/services only, which can be seen as an advantage for the reduction of the need for human resources.

As in regular LCA applications, HIS-LCA should be applied to each specific product/service separately, considering the position of the company in the production chain for that product/service, keeping in mind that a company may be an 'intermediate producer' and an 'end producer' at the same time, for a given product/service. The assessor ideally will be the technician who is responsible for the production of the given products or the supply of the services, within the company. The uncertainties will be handled as in the regular LCA studies. For a value, the range and type of distribution can be defined, and Monte Carlo analysis can be used accordingly. It should be recognized that in the case of all the probability distributions being a Gaussian distribution, Monte Carlo analysis is not necessary (Frey, 2007).

It should be noted that the complexity of the methodology is due to the efforts for developing a system that takes off the decision load from the assessor, hence it should not be perceived as a complication for the assessor. In contrast, the proposed system is designed to request the minimum information necessary to perform a comprehensive and case specific LCA automatically, by using an appropriate algorithm. In addition, the HIS-LCA interface should be designed to be easily understandable without leaving room for any doubts.
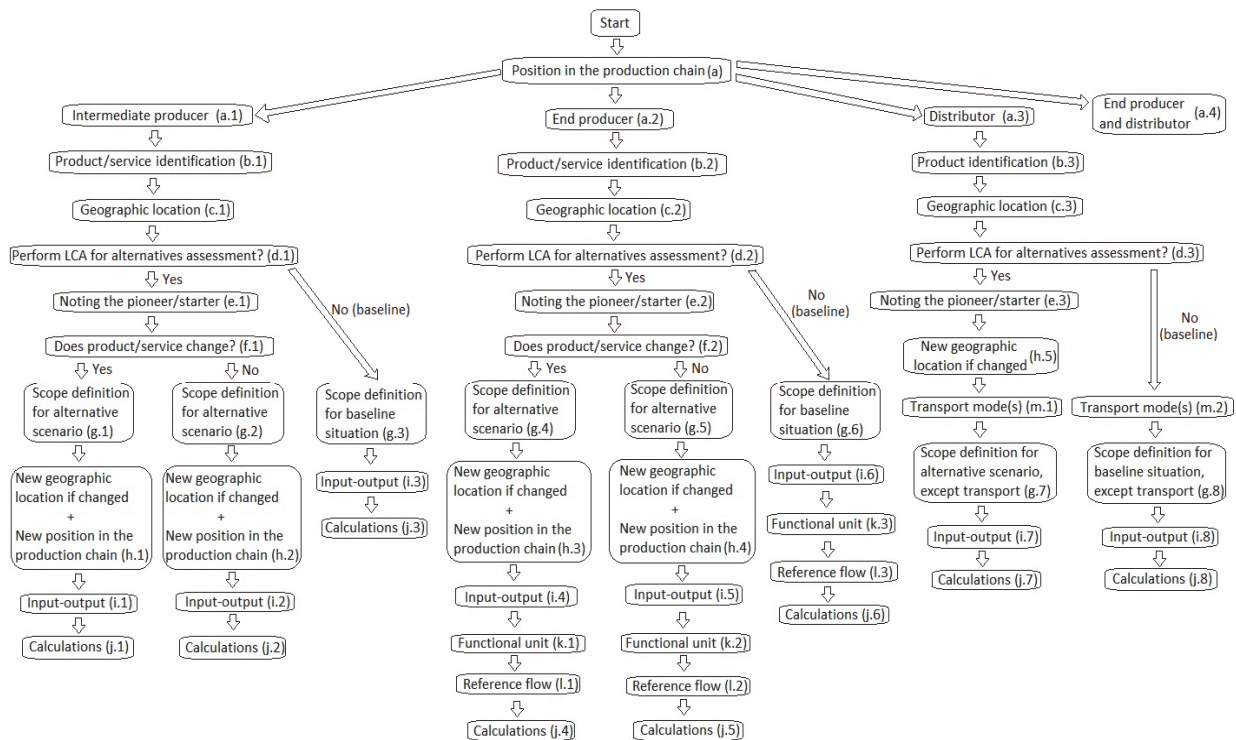

Fig. 1. Flowchart to be used for the case specific inventory formation

The assessors will be held responsible to know:

• their position(s) in the production chain for a given product/service (i.e. 'end producer', etc.),

• the yearly input-output data for each of their processes (for the assessors unable to obtain such information, an option will be available to select the regional industry average yearly elementary flow data for the products/services within the same category produced by similar technologies (please see section 3.2.). Here, 'elementary flow' means "Material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation" (ISO, 2006), with uncertainties if present (for uncertainties, the maximum-minimum values and confidence level will be necessary. If the confidence level is unknown, a default value (e.g. 90%) can be entered): inputs from nature (the amount, location and source type), inputs from the background system (the HIS-LCA product/service codes of input products/services, the transport mode(s) and yearly amounts of each of their input products), emissions (including the amount, location and the emission compartment) and waste (including the amount and treatment type). The technicians are held responsible to know:

• the main allocation methods,

• the efficiency of their products/services to perform a given function (for 'end producer' and 'end producer and distributor' only),

• the production technology of their products,

• the geographical location of their production processes (not for 'distributors'),

• the geographical distribution location for each product (not for 'intermediate producer' and 'end producer'),

• the basics of HIS-LCA (An educational video to be prepared).

The structure of the proposed system will be explained by following the LCA framework outline given in the ISO 14044 standard (ISO, 2006).

3.1. Goal and scope

The goal of HIS-LCA is to obtain life cycle environmental impact results to be used in the ecolabelling of products/services to inform the consumers, and for assisting alternatives assessment decisions made by companies. The scope is defined for different situations separately as shown in Fig. 2, Fig. 3 and Fig. 4. Recycling will be dealt with by cut-off method, as described in the Ecoinvent cut-off system model (Ecoinvent, 2017).

The usefulness of this approach is the harmonization of the scope definition, specific to each situation. The relevant inventories for the defined scope will be requested automatically by the proposed HIS-LCA program specifically for each case. The HIS-LCA will be able to know the scope by gathering information about the company and product/service as mentioned in the section 3.2.
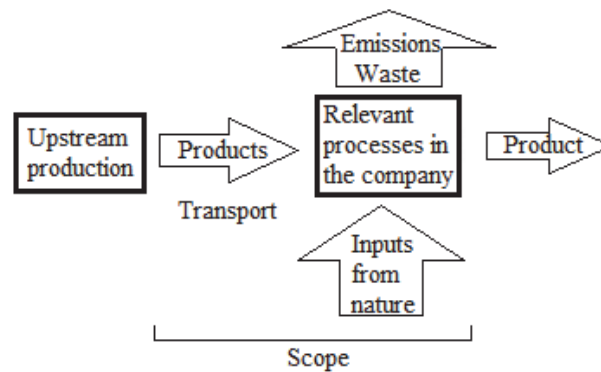

Fig. 2. Scope for the 'intermediate producer'/ Scope for the 'end producer' that supply a given service/ Scope for the 'end producer' for alternatives assessment scenario with no change in the product
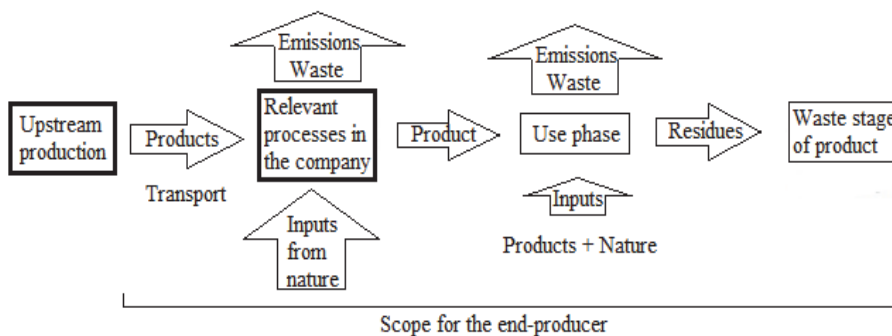

Fig. 3. Scope for the 'end producer' of a product for baseline scenario/ Scope for the 'end producer' of a product for alternatives assessment scenario with a change in the product
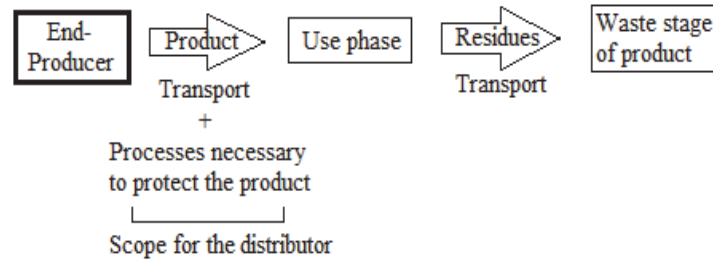
Fig. 4. Scope for the 'distributor'

3.2. Inventory

The approach of HIS-LCA to the inventory formation is different from the traditional approaches that use technology average data for the major part of their inventory (Hendrickson et al., 1998; Hertwich, 2005; ILCD, 2010). In the proposed system, the input-output matrix will consist of specific products/services rather than product/service categories. Solely for waste treatment, land occupation/transformation and transport, industry average data will be used to automatically derive the waste treatment, land use and the transport inventories (transport route and mode(s) will be marked on the geographical map).

In cases where the assessors are unable to identify their elementary flows, only the unknown part of the elementary flows will be completed by using the regional industry average data of the same products/services in the same category, produced by similar technologies, as the given product/service. It can be stressed that the degree of similarity in the production technology of the products/services can be examined with an indicator simply given as the number of common technologies used in the production of the products/services.

The information necessary to create the input-output matrix and the corresponding stressor inventory will be gathered by using the flowchart proposed in Fig. 1. The information entered to this flowchart will be saved to a database representing the baseline situation, from now on called 'product/service database'. In an alternative scenario, this database will be used as a default to be partly (i.e. each company can modify only their product/service information) presented to the assessor, to be modified and saved separately as 'alternative product/service database', for each alternative scenario. Once the alternative scenario is approved, it will be used to partly modify the former 'product/service database'.

A short explanation for each step of the flowchart shown in Fig. 1 is given in section 3.2.1. A comprehensive explanation presents, guiding the automation of requests from the assessor and handling of the data, but this could not be incorporated into this article due to length concerns.

3.2.1. Inventory formation

The algorithm developed for the case specific inventory formation consists of the following steps:

(a) steps: The assessor will select their position in the production chain for the baseline product/service for the existing situation, or for the product/service to be replaced in the alternative scenario, or for a new product that does not replace any baseline product(s)/service(s).

(b) steps: The assessor will select the product/service from the product/service database by a word search or a categorical system. If the product/service or its category does not present in the database, the assessor will be able to open a category and add the product/service name.

Assessors will also define the unit of product/service from suggested units defined in similar categories, and indicate if it is a service or a product. Also, the production technology will be selected similarly from the 'technology database' for a given product/service. 'End producer' will additionally enter the product composition after the use phase of a product (residues) and select among the functional units proposed (previously by other assessors in similar product/service category and type) for the product/service. In cases where the functional unit has not already been proposed, or the assessor has doubts, a request will be sent to the relevant experts for defining the functional unit. For the 'end producer', the product will also be categorized as 'consumption product' or 'products for use'.

'Consumption products' are the products that are actively consumed regardless of their expected lifetime (e.g. all food products, toilet paper, tooth paste, etc.). 'Products for use' are products that are used for a purpose, and which are not actively terminated (e.g. TV, fridge, car, furniture, etc.). 'Products for use' are expected to last for their expected lifetime. If this is the case, the expected lifetime (t) for the 'product for use' will be entered in the HIS-LCA. For consumption products and for all the services t will be set equal to 1.

(c) steps: Assessors will be responsible for marking the geographical location of the output gate of the defined product on a geographical map similar to 'google maps'. For service suppliers, the geographical location will be marked as the branch location.

(d) steps: 'Yes' will be selected in the situations where the assessor will change anything related to the production/distribution of the defined product/service, or to add a new product/service/distribution location that is not present in the baseline situation. A new alternatives assessment template will be opened with

default values as in the baseline situation, and multiple products/services can be modified as a result of the alternative scenario, and be evaluated as a whole.

(e) steps: In this step, the assessor will note that he/she started the alternative scenario (to ensure that the assessor recognizes that he/she is starting a new alternative assessment). For automatic suggestion as a 'warning' (requests for an alternative scenario) from upstream producers, this step will not be available.

(f) steps: Any change in the given product/service will be marked as 'Yes' and a 'warning' will be sent downstream to those that uses the defined product/service.

(g) steps: The relevant processes necessary to produce/supply the product/service will be determined by the assessor for the scopes defined in section 3.1.

(h) steps: Steps (a), (b) and (c) to be updated for the alternative scenario.

(i) steps: Input-output data for the defined scope will be entered for the defined product/service as in the usual LCA software. The technician will be responsible for the allocation of input-outputs. Hence, it is recognized that technicians will need a training on allocation techniques and the best practices available, such as the International Reference Life Cycle Data System (ILCD) recommendations (ILCD, 2010).

Input-output data include: yearly inputs from nature (the amount, location and source type), yearly inputs from the background system (the HIS-LCA product/service codes of input products/services, the transport mode(s) and yearly amounts of each of their input products), yearly emissions (including the amount, location and the emission compartment) and yearly waste (including the amount and treatment type). Land occupation/transformation will be included in the inputs from nature.

(j) steps: Calculations include complex algorithms (i.e. tracking along the input-output matrix, matrix multiplication, normalization of impact results by the percentage of the upstream permit (e.g. IPPC permit) holders among the mandatory ones, notification of other companies when necessary, uncertainty and impact calculations, etc.).

(k) steps: In cases where there is a problem with the functional unit definition in step (b) (i.e. the proposed functional unit is not appropriate, there is no established functional units for the product/service, etc.), the assessor will define the product/service in detail including its usage purpose and ask for further suggestions from expert teams.

(l) steps: This question will be asked to the assessor for the 'products for use': "One unit of my product can perform ...(F)... functional units in 1 year". This question will be asked to the assessor for the 'consumption products' or services: "One unit of my product/service can perform …(F)… functional units".

(m) steps: The distributor will determine the transport mode(s) for the alternative scenario, with the help of the geographical map tool.

The receivers of the 'warning' used for the alternative scenario proposal (steps (e) and (f)) will have the option to decline the request for an alternative scenario in cases where they do not agree with the change. In such cases, the receiver company will be presumed to continue using the original product/service. This approach assumes that the company which declines the change will replace their supplier with a similar technology to the original product/service. Hence, due to the deduction of the common inventory from the alternatives assessment, as will be mentioned in section 3.3, it will have no influence in the alternatives assessment results.

3.2.2. Infrastructure

The inclusion of the infrastructure into the inventory has been problematic due to the lack of product/service codes for recent infrastructure. Nevertheless, it can be stressed that over time (as products/services are assigned with codes) the inclusion of the infrastructure seems possible as the inventory for the infrastructure can be derived by using input/outputs originated from both the production and the use phase of the infrastructure, as well as the expected lifetime of the infrastructure. It can also be stressed that for the alternatives assessment, the timing for infrastructure change can be suggested by the HIS-LCA to minimize (or optimize) the density of the elementary flows in time, by using Monte Carlo analysis when multiple infrastructure changes are necessary.

3.3. Impact assessment

After all the steps are completed by the relevant companies, the Open Leontief model will be used as a well-established concept (Obikwere and Ebiefung, 2014) that is being used to link the external demands on the technosphere to the environmental stressors. The model will be used in the proposed system for the calculation of the environmental stressors inventory. An input-output matrix (i.e. requirements matrix) (A) as in Eq. (1) will be formed by using the data gathered by using the flowchart shown in Fig. 1.

$$A = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & a_{36} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} & a_{46} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & a_{56} \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66} \end{bmatrix} \begin{matrix} \text{End products/ services} \\ \\ \text{Intermediate products/ services} \end{matrix}$$

$$\underbrace{}_{\substack{\text{End products/}\\\text{services}}} \underbrace{}_{\substack{\text{Intermediate products/}\\\text{services}}}$$

(1)

For ecolabelling purposes, for a given 'end product/service' (here in the example, the second row), the external demand matrix (y) will be written as in Eq. (2):

$$y = \begin{bmatrix} 0 \\ 1/(F_2 * t_2) \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \begin{matrix} \text{End products/} \\ \text{services} \end{matrix}$$

(2)

where: *F* and *t* are the values defined in steps (b) and (l). For alternatives assessment purposes, a different external demand matrix will be used, such that it will include the demand of every 'end product/service' that is linked to the product(s)/service(s) affected by the alternative scenario. However, the end products/services that are positioned on a branch that has a company which declined the alternative scenario, will be excluded from this demand matrix. Proposed demand matrix (i.e. 'combined total functional demand') considers the total current demand of consumers for all the relevant functions. This is different from the traditional external demand matrix used in LCA studies, nonetheless it optimizes the technosphere in terms of life cycle environmental impacts. The logic of this method is that multiple products/services with different functions can be seen as a product/service system that is serving the total demand for those functions. The method encourages the alternative scenario in which the product/service system can provide the total functional demand (i.e. 'combined functional unit') relevant to those products/services with minimum total environmental impact. As an example, if the 'end products/services' 1 and 2 are linked to the product(s)/service(s) affected by the alternative scenario, the demand matrix will be as in Eq. (3) and Eq. (4).

In Eq. (3) and Eq. (4), *T* is the total yearly production amount of the end product/service, and subscripts 'old' and 'new' mean the baseline situation and the alternatives scenario, respectively. The production matrix (*X*) will be defined for each case as the multiplication of *y* with the Leontief Inverse $(I-A)^{-1}$. The elementary flows and stressors per unit production of each product/service can be represented as a stressor matrix (*S*). The *S* matrix will be formed by the inputs from the assessors. Only the transport, waste treatment and land occupation/transformation processes are planned to be generic. The total stressors matrix (*E*) for each product/service is obtained by multiplying *S* matrix with $\hat{X}$. $\hat{X}$ is simply a square diagonal matrix with diagonal values of *X*, and zero everywhere else. This separation is done not to lose the information on the origin of the elementary flows.

$$y_{old} = \begin{bmatrix} T_{1,old} \\ T_{2,old} \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \begin{array}{l} \text{End products/} \\ \text{services} \end{array}$$

(3)

$$v_{new} = \begin{bmatrix} (F_{1,old} * t_{1,old}) * T_{1,old}/(F_{1,new} * t_{1,new}) \\ (F_{2,old} * t_{2,old}) * T_{2,old}/(F_{2,new} * t_{2,new}) \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \begin{array}{l} \text{End products/} \\ \text{services} \end{array}$$

(4)

For ecolabelling purposes, the *E* matrix will be used to derive the life cycle environmental impacts of end products/services. For data quality concerns, the single impact score will be divided by the percentage of permit holders that are obligated for a permit, among all the linked companies to the end product/service. However, for alternatives assessment, firstly the common inventory (between E_{old} and E_{new} matrices) will be omitted (Fig. 5). This is done to overcome the unnecessary inclusion of uncertainties into the impact results. After this simplification, the life cycle environmental impacts (after division by the percentage of permit holders that are obligated for a permit, among all the linked companies to the product/service) will be presented to the assessor for the baseline situation and for the alternative scenario as a graph, with the uncertainties indicated. If the alternative scenario is accepted, each company, that at the same time comes just after the company that proposed the alternative scenario and that is linked to an end product/service with an increased environmental impact due to the alternative scenario, will be notified to consider changing their providers, as it is known that it was possible to provide the relevant function with less environmental impact.
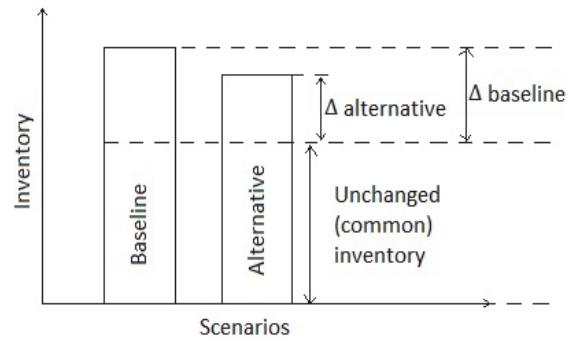

Fig. 5. A representation of common inventory of the baseline situation and the alternative scenario

Ideally the impact assessment will be performed for all the well-established impact categories by applying the state-of-the-art methodology for a given emission type and location (Ecoinvent, 2010; Hauschild et al., 2013). For ecolabelling, a single score is needed for simplicity, although ISO 14044 standard does not recommend reducing the impacts to a single score due to increase in uncertainty (ISO, 2006). It is recognized that this is not the case for alternatives assessment. For alternatives assessment purposes, it is possible to give an option to the assessor to choose either the midpoint impact or endpoint impact methodology, depending on the expertise of the assessor.

The data gaps regarding the impacts of the stressors and the extent of the stressor inventory are strictly a problem for the environmental impact experts to figure out the best practices on the subject, hence any data mining by the assessors themselves is discouraged.

3.4. Interpretation

In the use of ecolabelling, the interpretation is based on the single impact score per functional unit of the product/service. This score will be presented to the consumer similar to the price of the product/service, mentioning the functional unit as well (e.g. Liquid hand soap; life cycle environmental impact score per one hand wash). For the alternatives assessment, the assessor should evaluate the presented life cycle environmental impact results, with uncertainties in mind.

3.5. Discussion of the results

Although a cost-benefit analysis should be performed for shifting the weight of the responsibility towards companies (technicians), it can be stressed that the amount of expert input (time spent on LCA studies) necessary to implement such a wide range LCA is expected to highly surpass the efforts spent by the technicians using HIS-LCA, even if the education for HIS-LCA and the design and development of HIS-LCA itself are considered. In addition, it can be further stressed that the knowledge of technicians about the emissions in the company would be improved significantly.

The definition of the functional unit for each end product/service might be seen as an extreme work load for experts; however, for each product/service type, the functional unit will be defined only once and the assessors will be able to use the defined functional unit for their products/services without the need for a consultation (e.g. once the functional unit is defined for liquid hand soap, all the other liquid hand soap producers will be able to use this functional unit without any input from the experts). Hence, the consultations regarding the functional unit definition are expected to decrease with time.

The data quality concerns are mostly related to the allocation of the inventory, and to the assumptions about the lifetime of products and use patterns. It can be stressed that the expected lifetime of the end product (for "products for use") should be disclosed to the consumer to eliminate the concerns of misinformation about lifetime and to facilitate a more informed consumption. All the assessors can be deterred from declaring misleading information by occasional audits resulting in high penalties for those who mislead. In traditional LCA studies following ISO 14044 procedures, the reliability is established through 'critical review' process. However, the proposed system targets reliability through strictly predefined scope, audits, public disclosure of claimed information, such as lifetime and performance of products. Multifunctional end products are also a concern, as in the regular LCA studies.

In the case of the alternatives assessment, when the proposed alternative product/service system will have a different set of functional units than the original situation, it is necessary to perform the substitution method so that the performed functions will be equivalent for both the alternative scenario and the baseline situation. The substitution method also should be performed with appropriate algorithms, using the average LCI for a given function. For this, a regional average might be more meaningful to capture the habits of the local inhabitants (i.e. different cultures might signify different preferences on how a function is fulfilled; e.g. eating habits). The same argument can be held for the multifunctional end products, both in the alternatives assessment and in the ecolabelling practices.

The proposed system also acts as a driver towards a global permit acquisition (such as IPPC permit) by linking the lack of permit to consumer decision. International regulations should be in place for harmonizing the permit requirements among nations. Regulatory changes should be made to make the implementation of HIS-LCA mandatory, once the methodology has matured enough.

The location specific environmental impact assessments (e.g. spatial LCA) are already under a continuous development by many experts working in this field, with efforts to derive local characterization factors with the help of geographical data (e.g. Geographical Information System (GIS) (Hiloidhari et al., 2017; Mutel et al., 2012)), and these studies are crucial in the derivation of location specific environmental impact factors to be used in HIS-LCA. However, defining a method for the derivation of such characterization factors is not in the scope of this study, and is a separate study within itself.

The proposed system, with barcoding the products/services, has the potential to be used as an alternative currency, with minor modifications. In traditional LCA practices, the endpoint scores for human well-being are commonly represented in 'disability adjusted life years (DALY)' (WHO, 2017). As worker's time can be seen as a resource (as an input in the LCI), it is logical to aggregate these life years lost at work (with an appropriate weighting based on the satisfaction scores obtained by public polls) to the end point score of 'human well-being', as the units would be in 'years of life lost' in both cases. Hence it is possible to account for the worker's input and environmental well-being under the same roof.

Expected advantages of the proposed system: (1) wider application of LCA for environmental impact optimization, (2) companies might be able to assess where their impacts come from (transport, energy, etc.) and focus on these areas, (3) each company will be given a code, and company specific data can be followed, (4) improvement in the use of case specific information instead of industry average, (5) end product/service labelling by Life Cycle Impact Scores per functional unit, (6) LCA results, with uncertainty analysis incorporated, can be used in alternatives assessment, (7) no need to define functional unit for every company (only the end producers will be responsible for functional unit definition), (8) changes simultaneously affecting multiple end products/services can be evaluated based on the efficiency of the product/service system in fulfilling

the total demand for those relevant functions, (9) localization can be improved by mapping the industry on real geographical map, (10) product composition does not need to be disclosed by the company to be used for LCA purposes, (11) opportunity to improve allocation, (12) encouraging companies by consumer pressure to decrease their emissions, (13) an opportunity to be used as an alternative to traditional monetary system (which usually excludes environmental issues).

Also, the expected challenges are: (1) all the other problems with LCA still present (e.g. single products with multiple functionality, allocation, recycling, worker exposure, metals, nanoparticles, missing data, weighting, etc.), (2) some training might be needed (on understanding the functional unit, allocation, HIS-LCA basics, etc.), (3) expert support might be needed (just once for each product/service type) for functional unit definition, (4) regulatory pressures need to be in place; regulation changes, (5) recycling should be encouraged by regulation, (6) at the present time, for alternatives assessment, infrastructure cannot be incorporated into the methodology due to the lack of databases for the baseline infrastructure (not a problem for future applications), (7) terminology harmonization needed when passing information (e.g. product names, process names, etc.).

4. Conclusions

Expert systems approach for a wider implementation of LCA might be possible with further improvements mentioned in this study. The internet based open software development and free consultation service for functional unit definition inquiries should be established. Although many issues with the regular LCA studies are still present (e.g. multifunctional products, allocation, etc.); the wider application of LCA, reduction of resource intensiveness in terms of work time, and the harmonization of the scope are among the main benefits of the proposed system.

Furthermore, the proposed system has the potential to be used as an alternative currency, with mentioned minor modifications.

The localization also can be improved by mapping the whole industry (represented by products/services) on to the real geographical map. Hence, the proposed system can be stressed to be flexible for future development (to build on), and has the potential to solve some of the practical problems facing the application of LCA today. The further examination and implementation of the proposed system need a wider input from the scientific community towards the improvement and the application of the proposed system, as the methodology implementation requires an isolated and complete (including all life cycles) industrial system and cannot be examined locally in just a few companies.

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