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A framework for using the handprint concept in attributional life cycle (sustainability) assessment

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ABSTRACT

Handprint refers to the good society does for the environment, but this definition gives room for different interpretations. While in life cycle (sustainability) assessment (LC(S)A) its use is still at infancy, the effective communication potential of Handprint terminology gives room for increasing its application in the future. The objective of this article is to propose a framework to distinguish and classify various types of handprint, when they are intended to be used in LC(S)A studies. Building on the current structure of LC(S)A regarding the cause-effect chain, from flows to impacts, a framework to allow understanding the beneficial, adverse and net effects various flows can cause to different actors is created. Based on that, three handprint types are proposed, i.e., Direct, Indirect and Relative. These types can be subdivided into more specific/complex types of handprint, e.g., Indirect Relative Handprint (adverse). Illustrations with case studies (fictive and from literature) are used to suggest some guidance. With this proposal, a first step to consistently introduce the handprint concept into LC(S)A is achieved, but future challenges still exist (e.g., development of quantitative methods for beneficial impacts from product's functionality, in footprint-consistent units).

1. Introduction

Environmental sustainability assessment has historically focused on the negative impacts that products, services, systems, projects, etc. cause in the environment (Roy et al., 2009; Baldini et al., 2017). There are very few cases in literature in which the positive impacts of a product were quantified, and the methodology to do so is not so comprehensive. Meanwhile, in the last few years some researchers have emphasized the need for changing the business mindset, from focusing on reducing negative impacts to enhancing positive impacts (Grönman et al., 2019). In 2007, during UNESCO's 4th International Conference on Environment Education, in India, the concept of 'handprint' was launched (Handprint, 2019). Back then, it was described as actions towards sustainability; afterwards, a few more elaborated definitions arose.

According to Biemer et al. (2013), the (environmental) handprint refers to the good society does for the environment. Meanwhile, Norris and Phansey (2015) gave a more specific definition, where they stated that the handprint is the footprint-consistent estimate of the impacts of positive change. A few other publications gave similar definitions to the two former ones (Dyllick and Rost, 2017; ILFI, 2017). Focusing on a more particular type of environmental issue, Grönman et al. (2019) provided a definition for the carbon handprint, as the reduction of the carbon footprint for a customer (or customers).

The list of cases that would fit as a handprint can be very extensive. From local women planting thousands of trees for climate and water regulation (Handprint, 2019), to promoting paper recycling via placing recycling bins in strategic places or installing LED light to replace less efficient bulbs (Norris, 2018). Therefore, guidelines are needed for a proper use of the terminology.

Norris and Phansey (2015) stated that there are two ways to create a handprint: (1) Preventing and/or avoiding footprints that would otherwise have occurred, which includes reducing the magnitude of footprints that occur, relative to what their magnitude would otherwise have been; and (2) Creating positive benefits

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which would have not occurred otherwise. Moreover, Norris and Phansey (2015) introduced the term *NetPositive*, which is the result of a positive balance between handprint and footprint, i.e., if the handprint is larger than the footprint for a given impact category; the system becomes *NetPositive* for that impact category.

The handprint concept has slowly been introduced to the Life Cycle (Sustainability) Assessment (LC(S)A) community, which has happened mainly in two fronts. On the one hand, a few studies clearly mentioned the 'handprint' concept (Grönman et al., 2019; Pajula et al., 2017). On the other hand, other studies developed tools to quantify the positive benefits that products bring to their intended users, but not clearly naming them as 'handprint', as Debaveye et al. (2016) and Debaveye et al. (2019) for studies in the health care sector, or Saarinen et al. (2017), Springmann et al. (2016) and Stylianou et al. (2016) for studies in the food sector.

Nevertheless, when referring to the handprint term in LC(S)A studies, a few misunderstandings may arise. One may argue that handprint is not captured at all in LC(S)A. Others may say that handprint is already captured through the specific Functional Unit (FU) of the LC(S)A study. Moreover, other ones may argue that it is fully captured in LC(S)A, when performing comparative studies and/or addressing the avoided burden approach. Well, it is possible that these three groups are correct but, in fact, they are talking about slightly different things. Therefore, the objective of this article is to create a framework to distinguish and classify different types of handprint, when they are intended to be used in LC(S)A studies. Even though the handprint concept is still in its infancy, it has a high potential to be used in LC(S)A studies for communication purposes (as it has happened with the term *footprint* in the last decade). In the following section 2, the development of the handprint classification framework is presented, starting from a cause-and-effect analysis (section 2.1). Based on that, the beneficial, adverse and net effects are tabulated (section 2.2), enabling to provide a handprint classification (section 2.3), and further discussed (section 2.4). In the subsequent sections, the framework is illustrated with examples (section 3) before being closed with a conclusions and outlook section (section 4).

2. Development of the handprint classification framework

2.1. Starting point of the classification: analysis of cause-and-effect chains

The LC(S)A of a product (good or service) accounts for the flows throughout its life cycle, from cradle-to-grave, including extraction, production, use and end-of-life. When these flows cross the boundary between nature (or natural environment) and technosphere (or man-made environment), they are known as elementary flows, and their compilation corresponds to the life cycle inventory (LCI) of the product. The elementary flows in an LCI are mainly producing adverse effects to the environment and society (e.g., CO_2 emissions). However, some of these elementary flows may generate beneficial effects to the environment and society (e.g., CO_2 absorption by photosynthesis in systems of the technosphere). Fig. 1 simply illustrates the cause-and-effect relationship between flows and their beneficial or adverse effects (following a similar structure from Mancini et al. (2018) for the description of the contribution of raw materials to the sustainable development goals).

During the use phase, the product's functionality can generate benefits to the product's (final) user(s), which are often not captured in the LCI (i.e., not by the elementary flows). The main functions of the product are usually quantified in the FU; however, there may be additional functions that are not considered. For instance, the FU of a television could be "*one unit of television set device*" (Song et al., 2012), but the excitement features, such as slim screen profile of LCD (changing the way TVs are installed and used), are not captured (Kim et al., 2017) in this FU. Moreover, these functions can bring benefits to different users, i.e., the intended user (IU) but also other users can be (positively) affected, which from now on will be referred to as unintendedly affected subjects (UAS). For example, a bus passenger may be the IU of a bus, but the bus driver, its mechanics, cleaners, etc., are other users/subjects that are affected by this product/service as well (Goedkoop et al., 2018), thus UAS. All the functions (main functions and additional functions) can affect different users (IU or UAS), and these benefits are not (fully) captured in the LCI, yet generating beneficial impacts (e.g., human health or human well-being). These flows are represented as dotted-lines in Fig. 1, from use-phase to functionality, and then to the (beneficial) impact.

The explanation in the two previous paragraphs is focused on a single product, i.e., comparison of a product with its non-existence. Thus, any beneficial impact in a product system can be interpreted as the *second way* of creating a handprint according to Norris and Phansey (2015), i.e., creating positive benefits which otherwise would not have occurred. Furthermore, two (or more) products may be used in a comparative LC(S)A study, using the same FU, where their beneficial and/or adverse impacts would be confronted (the beneficial and adverse impacts could either be created by the elementary flows, the product's functionality, or other flows). In case one product has lower adverse impacts than another (e.g., lower carbon footprint), this analysis may be interpreted as the *first way* of creating a handprint according to Norris and Phansey (2015), i.e., preventing and/or avoiding footprints that would otherwise have occurred. With this background in mind, a framework is created to support the classification of handprint types, as explained in the following section.

2.2. Classification framework of effects

To better understand beneficial and adverse effects on different users and subjects (IU and UAS); and, how they can be compared to the product's non-existence or to another product, a framework is developed, which can be seen in Table 1.

The variables used in Table 1 refer to the absolute beneficial (B), adverse (A) or net (N) value of the impact. The latter variable (N) is the result of the beneficial value (B) minus the adverse value (A), which can be in the same units (e.g., Disability Adjusted Life Years – DALY) or not. The latter case (different units) would require making use of aggregation techniques, such as ISO 14040's optional steps for impact assessment (normalization, grouping and weighting), or multi-criteria decision analysis, amongst others. When the variable starts with a delta (Δ), it is the difference between the absolute value of the product compared to a reference product. For instance, ΔA is the difference between A from a certain product "X", and A from another product "Y". The subscript letters refer to "from what" and "to what" these effects are playing a role, respectively, i.e., if it is from the product's functionality (P) (e.g., food nutritional value) or from the intervention[a] flows (I) (e.g., emissions at supply chain), and if it is having an effect on the IU or on the UAS. The variables can also be consistently summed with each other, generating relevant information. For instance, the sum of $\Delta N_{P,IU}$ and $\Delta N_{I,IU}$ would generate the net effects to IU, while their sum with $\Delta N_{P,UAS}$ and $\Delta N_{I,UAS}$ would generate the net effects to IU and UAS together (for more details, check section 2.3). This framework can be applied to

[a] Intervention flows are defined as flows (tangible or not) going in or out the system boundaries and which result in a beneficial or negative effect on IU or UAS. They can be elementary flows (as in LCA), but include other economic and non-physical flows as well.

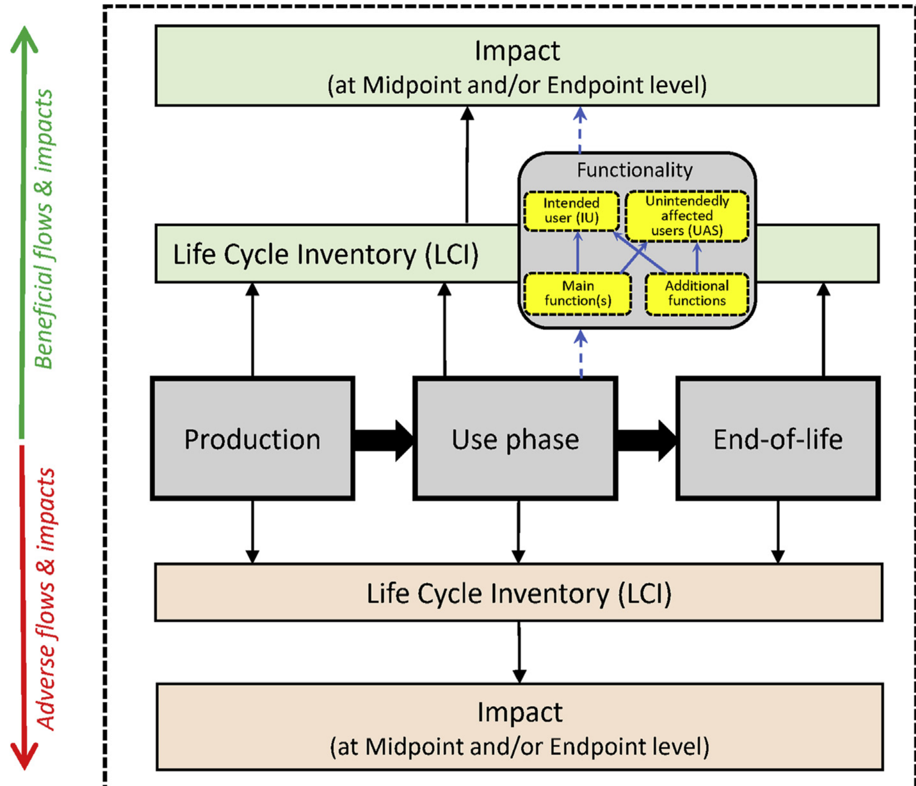

Fig. 1. Simplified cause-and-effect relationship of flows and impacts in a generic life cycle of a product.

Table 1
Classification framework for beneficial, adverse and net effects, from product's functionality or intervention flows, to on intended users or unintendedly affected subjects.

Nature of evaluation	Effect	Intended User (IU)		Unintendedly affected subjects (UAS)	
		From product's functionality (P)	From intervention flows (I)	From product's functionality (P)	From intervention flows (I)
Single product information	Beneficial (B)	$B_{P,IU}$	$B_{I,IU}$	$B_{P,UAS}$	$B_{I,UAS}$
	Adverse (A)	$A_{P,IU}$	$A_{I,IU}$	$A_{P,UAS}$	$A_{I,UAS}$
	Net (N)	$N_{P,IU}$	$N_{I,IU}$	$N_{P,UAS}$	$N_{I,UAS}$
Comparative information (Δ)	Beneficial (B)	$\Delta B_{P,IU}$	$\Delta B_{I,IU}$	$\Delta B_{P,UAS}$	$\Delta B_{I,UAS}$
	Adverse (A)	$\Delta A_{P,IU}$	$\Delta A_{I,IU}$	$\Delta A_{P,UAS}$	$\Delta A_{I,UAS}$
	Net (N)	$\Delta N_{P,IU}$	$\Delta N_{I,IU}$	$\Delta N_{P,UAS}$	$\Delta N_{I,UAS}$

any type of product, as shown in section 3. Moreover, not all types of effects are necessarily accounted in all products (e.g., product X may have impact values for $A_{P,IU}$, while product Y may not have). This nomenclature is detailed in the section Nomenclature list.

2.3. *From effects classification to definition of handprint types*

Based on the previously presented framework, and by aggregating some variables from Table 1, three types of Handprint definitions are proposed: (i) Direct Handprint; (ii) Indirect Handprint; and (iii) Relative Handprint, which are explained below.

2.3.1. *Direct handprint*

The Direct Handprint is defined as *the (absolute) positive impacts that a product can bring to its IU, due to the product's functionality and/or due to the intervention flows*. Whenever possible, the beneficial and the adverse effects should be considered in the same unit, thus, it would be the sum of $N_{P,IU}$ and $N_{I,IU}$ (Eq. (1)). Of course, it should be named handprint only if the sum generates net beneficial results. However, as it will not always be possible to consistently calculate the adverse effects to the IU, one may consider solely the beneficial effects to the IU as the Direct Handprint, i.e., the sum of $B_{P,IU}$ and $B_{I,IU}$ (Eq. (2)). In order to differentiate them, the term Net Direct Handprint for the former and Partial Direct Handprint for the latter are suggested.

$$\text{Net Direct Handprint} = N_{P,IU} + N_{I,IU},\ \text{if} > 0^{b} \quad (1)$$

$$\text{Partial Direct Handprint} = B_{P,IU} + B_{I,IU} \quad (2)$$

A few examples of Direct Handprint (Net and/or Partial), with the specific impact category between brackets, are:

- Benefits to the IU due to ingestion of certain food (human health) (Saarinen et al., 2017; Springmann et al., 2016; Stylianou et al., 2016)

[b] Considering a direction as in Fig. 1, i.e., where beneficial/effects impacts have positive values and adverse impacts/effects have negative values (which is the opposite from typical LC(S)A results).

- Benefits to the IU (patient) from taking a certain drug (human health) (Debaveye et al., 2016);
- Benefits to the IU from using a bicycle as means of transportation (human health; well-being);
- Benefits to the IU (a paraplegic person) by making use of a wheelchair (well-being).

2.3.2. Indirect handprint

The Indirect Handprint is defined as *the (absolute) positive impacts that a product can bring to UAS, due to the product's functionality and/or due to the intervention flows*. Similarly to the previous handprint type, one may calculate the indirect handprint through the sum of the beneficial effects ($B_{P,UAS}$ and $B_{I,UAS}$) or the sum of the net effects ($N_{P,UAS}$ and $N_{I,UAS}$) (Eq. (3) and Eq. (4)). For consistency, it is suggested to follow the same nomenclature as the direct handprint, i.e., partial for the former and net for the later.

$$\text{Net Indirect Handprint} = N_{P,UAS} + N_{I,UAS}, \text{ if} > 0 \tag{3}$$

$$\text{Partial Indirect Handprint} = B_{P,UAS} + B_{I,UAS} \tag{4}$$

Mostly in LC(S)A, some beneficial effects (e.g., $B_{I,UAS}$) are already counter-balanced with adverse effects (e.g., $A_{I,UAS}$), as it typically happens with the carbon footprint. This is more usual when dealing with flows from the background system, i.e., from life cycle inventory databases (e.g., Ecoinvent). For instance, beneficial effects $B_{I,UAS}$, such as biogenic carbon dioxide sequestration, are accounted for and counter-balanced with adverse effects $A_{I,UAS}$, such as fossil carbon dioxide emissions, generating the carbon footprint of the product, which would be the $N_{I,UAS}$ (in this case, focused on climate change). Therefore, it only makes sense to call this "carbon footprint" as Net Indirect Handprint, if the former has a negative sign (e.g., carbon footprint = −5 kg CO_2eq), which means a net beneficial result.

A few examples of *footprint-consistent* Indirect Handprint (Net and/or Partial), with the specific impact category between brackets, are:

- The absorption of NO_x when using TiO_2 as coating material in buildings (generating a benefit for terrestrial acidification) (Pini et al., 2017);
- Carbon sequestration during production phase, of biofuels (generating a benefit for climate change);
- Increase in pollination during honey production (generating a benefit for ecosystem services);
- Increase in local biodiversity from offshore wind turbines (generating a benefit on local biodiversity), during electricity production (Inger et al., 2009).

2.3.3. Relative handprint

The Relative Handprint is defined as *the (relative) positive impacts that a product can bring in comparison to a benchmark, for the IU and/or the UAS, due to the product's functionality and/or the intervention flows*. Thus, it refers to the last three lines of Table 1. Due to its broad application, two subtypes are suggested, i.e., (a) Direct Relative Handprint and (b) Indirect Relative Handprint. Both can, one more time, be each subdivided into three subtypes regarding their effects, i.e., beneficial, adverse and net; according to the equations below (Eqs. (5)–(10)).

$$\text{Direct Relative Handprint (beneficial)} = \Delta B_{P,IU} + \Delta B_{I,IU} \tag{5}$$

$$\text{Direct Relative Handprint (adverse)} = \Delta A_{P,IU} + \Delta A_{I,IU} \tag{6}$$

$$\text{Direct Relative Handprint (net)} = \Delta N_{P,IU} + \Delta N_{I,IU} \tag{7}$$

$$\text{Indirect Relative Handprint (beneficial)} = \Delta B_{P,UAS} + \Delta B_{I,UAS} \tag{8}$$

$$\text{Indirect Relative Handprint (adverse)} = \Delta A_{P,UAS} + \Delta A_{I,UAS} \tag{9}$$

$$\text{Indirect Relative Handprint (net)} = \Delta N_{P,UAS} + \Delta N_{I,UAS} \tag{10}$$

The relative handprints (all subtypes) are usually calculated via subtracting the absolute handprint of the benchmark from the absolute handprint of the studied product. Therefore, in all cases, the relative handprints are only handprints when this subtraction has a positive sign, representing a delta benefit. In other cases, with negative signs (represent a delta adverse result), the benchmark product is more beneficial. More clarity on this issue can be found with the illustrative case study, in section 3.2).

Moreover, using the Relative Handprint terminology in line with the definition from Grönman et al. (2019) for climate change is suggested, i.e., to use it only when communicating the potential reduction one product can create at a customer's footprint. In other words, a material (or intermediate product) bringing (relative) benefits at a final application. Therefore, the Relative Handprint terminology is not recommended for the results of traditional comparative LC(S)A studies, where its focus would be on the end product (downstream) with potential upstream benefits. For instance, the terminology Relative Handprint should not be used to communicate the difference in climate change impacts in a comparative LC(S)A study of plastics using two raw material sources (fossil-based and biobased) (Alvarenga et al., 2013). On the other hand, the terminology may be used by, for example, the biobased raw material manufacturer to highlight the potential benefits it can bring to its customer downstream, i.e., the plastic industry.

A few examples of Relative Handprint, considering the suggestion from the previous paragraph and based on *footprint-consistent* indicators, with the specific impact category between brackets, are:

- High-efficient batteries, in comparison to low-efficient ones, to be used for electric cars (benefits in several impact categories);
- Benefits from wind power, in comparison to other sources of power, for the electric mix of a certain region (benefits in climate change, amongst others);
- Compostable plastic, in comparison to traditional plastic, for short-life plastic bags (benefits in climate change, amongst others);
- Algae for fuel, in comparison to other fossil sources, for transportation (benefits in climate change, amongst others);
- Double-glass, in comparison to single-glass, to improve energy efficiency in buildings (benefits in several impact categories).

2.4. Overview and discussion on the handprint types

Fig. 2 summarizes how the proposed terminology for handprint would fit into the framework (Table 1). It is divided in a generic and specific division, as previously explained.

Depending on the goal of the LC(S)A study, one may use the more simplified/generic handprint terminology (i.e., Direct Handprint, Indirect Handprint or Relative Handprint) or the more precise/specific terminology (e.g., Partial Direct Handprint, Indirect Relative Handprint (adverse), amongst others).

Furthermore, the definition of additional adjectives can be relevant as well. For instance, if a handprint analysis (and communication) is focused only on one impact category, e.g., climate change or biodiversity, they can be added to the handprint terminology (e.g., Indirect Biodiversity Handprint). In fact, this is

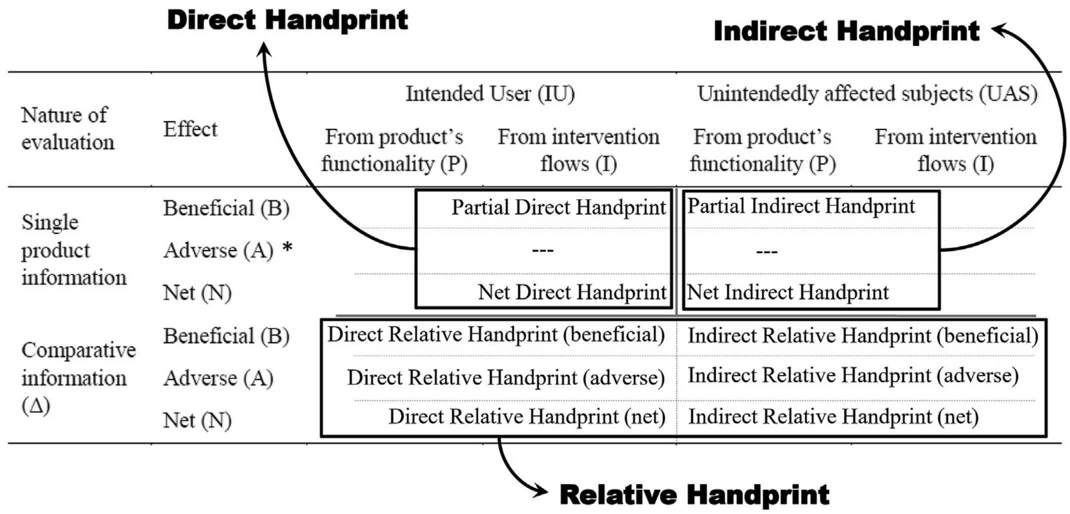

Fig. 2. Handprint types fit into the proposed framework.
* The values from Adverse (A) effects (in single product information) are not handprint, but may be used to generate the Net (N) effects, which are a handprint type.

the main difference between the proposal from this article and the one from Grönman et al. (2019), which is limited to Climate Change. Grönman et al. (2019) considered only one (sub)type of Handprint in their proposal, defined in this article as Indirect Relative Handprint (adverse), but made use of "climate" in the terminology. Even though the proposed terminology can be more complex, it has the advantage to be more precise. For instance, the carbon sequestration from trees, in a forest, can be captured by the approach proposed in this article, as Partial Indirect (Climate) Handprint, without the need of another product/reference.

While Norris and Phansey (2015)'s definition of handprint mentioned the use of *footprint-consistent* results, it can be noticed that in the framework this may not always be possible for potential benefits. For instance, for the case of the electric car, the mobility's benefits cannot be measured using *footprint-consistent* units. However, this would indeed be possible for a few other cases, such as the vegan-meal case and the medicine for schizophrenia cases. It is possible to quantify the impact on health quality of the IU (caused either by food or by medicine consumption) in Disability-Adjusted Life Years (DALY) (Stylianou et al., 2016) or in Quality-Adjusted Life Years (QALY), a similar metric to DALY (Debaveye et al., 2016). This supports the understanding of why the handprint concept, as defined by Norris and Phansey (2015)'s *second way* of creating handprint, grew mainly in LC(S)A studies related to food and health sectors.

The effects on the UAS, independently if it was caused by intervention flows (I) or by product's functionality (P), is commonly called *externality* in Economical Science. Externalities can be negative or positive, and can happen at the consumer or at the producer (Hutchinson, 2017). In parallel to the proposed framework, effects on the UAS can be beneficial or adverse, and can be due to the functionality of the product or from intervention flows.

While a product may have several users during its use-phase e.g., primary, secondary, tertiary, passive users (Goedkoop et al., 2018), it was preferred in this article to simplify this distinction between intended and others. Moreover, while the UAS from the proposed framework considers everybody else apart from the IU, e.g., the rest of society or the natural environment, it may often consider marginally the IU as well. For instance, decreasing the CO_2 emissions from e-cars, which would be captured by the sum of $\Delta A_{P,UAS}$ and $\Delta A_{I,UAS}$, would affect the entire society, including the IU. Therefore, it should be considered with care to avoid double-counting with, in this case, the $\Delta A_{P,IU}$ indicator. Ideally, to avoid potential double-counting, the P,IU indicators (e.g., $\Delta A_{P,IU}$) should consider the effects that are exclusive to the IU, leaving the effects that are common to UAS and IU to the P,UAS and I,UAS indicators (e.g., $\Delta A_{P,UAS}$ and $\Delta A_{I,UAS}$, respectively).

The I,IU indicators (e.g., $B_{I,IU}$) seem to be mostly related to feelings/sensations, thus, non-physical flows. Although they are usually not considered in LC(S)A, some discussions in this field have been considering indicators such as "happiness", which could fit there (Schaubroeck and Rugani, 2017). Nevertheless, you may have feelings/sensations in other indicators as well, for instance, food taste should be captured in $B_{P,IU}$.

Normally, the *net* values (e.g., $N_{P,IU}$) may be calculated by simple arithmetic's, in case the beneficial and adverse effects are expressed in the same units. However, more complex calculation procedures may be required, including the use of ISO 14040's optional steps for LCIA, i.e., normalization, grouping and weighting. Moreover, the delta values are only possible to be calculated if the absolute values of the compared products were calculated beforehand. Therefore, the delta values come at a second stage on the procedure.

It is important to mention that this approach is in line (and in a complementary perspective) with the Footprint concept and LCA framework. For instance, in the goal and scope definition, it is defined which handprint types may be included in the study, in the inventory analysis the necessary data will be collected (depending on the impact assessment method). Actually, the only area in Fig. 2 without handprint types is related to the adverse effects of single product information, which are in fact the footprints of those products. Moreover, the data requirements for implementing the framework and the handprint types are equivalent to the data requirements of attributional LC(S)A, considering that it will not always be possible to have quantitative values for all the parameters of Table 1, e.g., $B_{P,IU}$.

Finally, one may calculate a product handprint based on multiple beneficial and adverse effects. This means that one study could focus on one beneficial effect (e.g., human health) and include adverse effects, while another study on the same product could focus on two different beneficial effects (e.g., human health and happiness) and the same adverse effects. Consequently, the comparison of their results may not be straightforward. This can be understood as a similar issue as the choice of different environmental impact categories (including differences at midpoint and

Table 2
Implementing the case study from milk versus SSB, from (Stylianou et al., 2016), represented in μDALY/person/day for a functional unit of 498 kJ (or 119 kcal).

Nature of evaluation	Effect	Intended User (IU)		Unintendedly affected subjects (UAS)	
		From product's functionality (P)	From intervention flows (I)	From product's functionality (P)	From intervention flows (I)
Single product information (milk)	Beneficial (B)	**+2.0**[a] (+1.1 + (+0.9))	–	–	–
	Adverse (A)	**−0.3**	–	–	**−0.7** (−0.4 + (−0.3))
	Net (N)	**+1.7**	–	–	**−0.7**
Comparative information (Δ = milk − SSB)	Beneficial (B)	**+2.0**[b]	–	–	–
	Adverse (A)	**+3.2**[c]	–	–	**−0.5**[e]
	Net (N)	**+5.2**[d]	–	–	**−0.5**[e]

SSB = Sugar-sweetened beverages.
[a] The sign represents if the value is beneficial (+) or adverse (−).
[b] 2.0 = 2.0–0.
[c] 3.2 = −0.3 − (−3.5).
[d] 5.2 = 2.0 + 3.2 (or 1.7 − (−3.5).
[e] −0.5 = −0.7 − (−0.2).

endpoint indicators) in separate LCA studies. Nevertheless, this may be tackled by providing transparency in the intermediate and final results, and even with product category rules (PCRs) recommendations, to ease comparisons.

3. Illustration of the framework through case studies

In this section, some case studies are discussed as a validation of the development of the proposed classification framework. In a first subsection, three cases are analyzed, i.e. food, mobility and health care examples, in terms of the involved cause-and-effect chains in function of the resulting effects they generate, as classified in Table 1 (in the SM it is included the description of each case in qualitative tables, similar to Table 1). In a second subsection, a food case study in function of the developed handprint classification (Table 2) is elaborated, resulting in quantitative handprints. The case studies are different because they have different purposes, i.e., in section 3.1 the framework was applied extensively in order to test it in different products and sectors, while in section 3.2 the framework was applied into a more specific, practical, example.

3.1. Analysis of net effects

3.1.1. Case study from the food sector: locally-produced vegan meal

In this example, a vegan meal is considered, for which most of the ingredients are produced by local farmers. The comparative benchmark is a meat-based meal. When comparing the vegan meal to its non-existence (i.e., analysis of a single product), $B_{P,IU}$ can be the increase on health quality from ingestion of food components with positive health effects (e.g. fibers); $A_{P,IU}$ can be the decrease on health quality from ingestion of other food components (e.g., excess of saturated fat); and $N_{P,IU}$ is the net health quality from the ingestion of such (entire) meal. Socio-economic benefits to local farmers, e.g., human welfare, are represented by $B_{I,UAS}$, as this benefit is not coming from the functionality of the product, but from economic flows happening within its value chain. Moreover, it is affecting another user than the IU. The environmental impacts in the value chain (e.g., expressed in kg CO_2eq/meal), traditionally measured in LC(S)A, are represented by $A_{I,UAS}$. In case the LC(S)A brings the beneficial and adverse impacts into a single score result, e.g., via normalization and weighting, it would be represented in $N_{I,UAS}$. Moreover, if the IU feels happier during consumption by the satisfaction of supporting local farmers, this would be considered as $B_{I,IU}$. Even though the latter has rarely (or never) been considered in LC(S)A studies because it is a non-physical flow (satisfaction is someone's feeling, and therefore very subjective), it is kept in the example to support the framework's illustration.

When comparing to another product, i.e. a meat-based meal, several differences between the absolute values from the locally produced vegan meal and the benchmark may arise:

- *Product's Functionality to IU*: The difference in beneficial impacts ($\Delta B_{P,IU}$) takes into account the difference in positive/beneficial health quality to the IU, when choosing for one vegan meal over meat-based meal. For instance, the benefits from ingesting more fibers (in vegan meal) and from ingesting nutrients found in meat (e.g., iron and zinc). Meanwhile, the difference between the adverse impacts ($\Delta A_{P,IU}$) also takes into account the differences in health quality to the IU, but now focused on the adverse effects. For instance, the increased risk of heart disease and diabetes (in meat meal), while (assumed) no adverse effects for vegan meal (null values $A_{P,IU}$). Furthermore, the net value to the IU from product's functionality ($\Delta N_{P,IU}$) would be calculated as the difference between the two previous variables ($\Delta B_{P,IU}$ and $\Delta A_{P,IU}$).
- *Intervention flows to UAS*: The difference in socio-economic benefits, i.e., from a locally produced vegan meal versus (non-locally produced) meat-based meal, would be captured in $\Delta B_{I,UAS}$ [c]. On the other hand, the difference in environmental impacts (e.g., carbon footprint, acidification, land use, or overall single score) would be captured by $\Delta A_{I,UAS}$. Consequently, depending on the aggregation procedure, a $\Delta N_{I,UAS}$ could, in theory, be calculated.
- *Intervention flows to IU*: In the example, it is considered that locally-produced vegan meal had only $B_{I,IU}$ (and null values for $A_{I,IU}$). Furthermore, it may be assumed that the same IU would have an adverse feeling towards meat consumption (e.g., feeling dissatisfaction due to animal welfare and/or environmental impacts) and positive feelings towards supporting the business of his neighbor butcher, i.e., non-null values for $B_{I,IU}$ and $A_{I,IU}$ for meat-based meal. In this example, $\Delta B_{I,IU}$ would be the difference between satisfaction of supporting local farmers and satisfaction from supporting his neighbor butcher, while $\Delta A_{I,IU}$ would be equal to the $A_{I,IU}$ for meat-based meal (as a null value for locally-produced vegan meal is assumed). Consequently, the

[c] It should be acknowledged that the complexity of properly measuring socio-economic impacts in this example. Nevertheless, this is not discussed in this article because it is out of the scope.

indicator $\Delta N_{I,IU}$ would, in theory, calculate the delta net value of these feelings.

The effects due to intervention flows to IU ($_{I,IU}$) are not commonly quantified in LC(S)A nowadays, however, values from the effects of product's functionality to IU ($_{P,IU}$) and intervention flows to UAS ($_{I,UAS}$) have already been calculated in previous LC(S)A, although in an aggregated format (Stylianou et al., 2016).

3.1.2. Case study from the mobility sector: electric car

In this illustrative case of an electric car, first, some of the benefits and adverse effects of this product to society (IU and UAS) are considered. Second, a comparison with traditional diesel-based cars is made. The potential increase in the mobility of the IU would be captured by $B_{P,IU}$, while some adverse effects (e.g., costs for operation and maintenance) would be captured on $A_{P,IU}$. Consequently, the $N_{P,IU}$ is the theoretical net value between these two effects. The additional benefits to other users (UAS), e.g., allowing the increase in long-distance delivery services, shall be captured by $B_{P,UAS}$; while the marginal increase on traffic jam may be quantified by $A_{P,UAS}$. Finally, adverse environmental and socio-economic impacts throughout the value chain (e.g., carbon footprint or social impacts at lithium mines) would be captured by $A_{I,UAS}$; while beneficial socio-economic impacts (e.g., job creation) could be captured by $B_{I,UAS}$.

After doing the same exercise for the benchmark, i.e., diesel-based cars, one could calculate the comparative/relative terms, expressed by indicators starting with the delta (Δ). For instance, marginal lower exposure of the IU to particulate matter would be captured by $\Delta A_{P,IU}$. The overall change on particulate matter, carbon dioxide, noise, etc., during the use phase of the car (thus, due to product's functionality) would be captured by $\Delta A_{P,UAS}$, as this is affecting mainly the UAS. The change in the same flows during other life cycle stages than use phase (e.g., production phase) would be captured by $\Delta A_{I,UAS}$. Typical comparative LCA studies on electric car consider the sum of $\Delta A_{P,UAS}$ and $\Delta A_{I,UAS}$ (the latter, sometimes partially).

3.1.3. Case study from the healthcare sector: medicine for schizophrenia

All effects to the patient having schizophrenia, i.e., who is consuming the medicine, would be considered at the functionality of the product to the IU (i.e., $B_{P,IU}$, or $A_{P,IU,}$ or $N_{P,IU}$). The increase in quality of life of the patient would be the $B_{P,IU}$, the side effects (e.g., weight gain and seizures) would be in the $A_{P,IU}$, and the $N_{P,IU}$ would be the net value of these two effects. Moreover, the increase in the quality of life of the patient's family could be measured in $B_{P,UAS}$, while the adverse effects from the high costs of the medicine (for the patient's family) could be measured in $A_{P,UAS}$. Consequently, the $N_{P,UAS}$ is the theoretical value that captures both effects. Finally, the environmental impacts from the medicine's value chain (e.g., carbon footprint or freshwater ecotoxicity) are captured by $A_{I,UAS}$.

All relative effects when comparing two different (but similar) medicines would be captured on the corresponding indicators that start with a delta (Δ). For instance, a comparison of the side effects from consuming the medicine would be measured by $\Delta A_{P,IU}$, while the difference in carbon footprints of the production of the two different medicines would be captured in $\Delta A_{I,UAS}$.

3.2. Illustration of the quantification of different handprint types: food example

To demonstrate how the framework and proposal for handprint types (and terminologies and quantification) would fit into specific/real cases, a case study (available from literature) from the food sector that (indirectly) addressed the issue of handprint is used. Stylianou et al. (2016) evaluated the beneficial and adverse effects of introducing more milk in societal diet, including as substitute for sugar-sweetened beverages (SSB), by analyzing different scenarios. The nutritional health effects were combined with the human health adverse effects through the DALY indicator. The analysis focuses only on the results of scenario C, from figure6 of Stylianou et al. (2016), which are represented in Table 2. Important to notice that the numbers considered in this article are approximations from Stylianou et al. (2016), due to the lack of precision obtained from the aforementioned figure.

For a functional unit of 498 kJ (or 119 kcal) of nutritional value, the adverse effects of introducing more milk were quantified for climate change (~−0.4 μDALY/person/day) and particulate matter (~−0.3 μDALY/person/day), but also for the increased risk of prostate cancer (~−0.3 μDALY/person/day). On the other hand, the beneficial nutritional health effects from introducing more milk were also quantified, i.e., reduced risk of potential colorectal cancer (~+1.1 μDALY/person/day) and strokes (~+0.9 μDALY/person/day). Moreover, production of SSB had adverse effects for climate change and particulate matter (the sum was equal to approximately −0.20 μDALY/person/day) and potential nutritional adverse health effects from SSB-related diseases (~−3.5 μDALY/person/day). Of course, the nutritional effects are from the product's functionality on the IU, while the effects from climate change and particulate matter are from intervention flows on UAS. Other effects (e.g., from product's functionality on UAS) were not accounted for.

As a result of this, the milk analyzed in the case study has a Net Direct Handprint of +1.7 μDALY/person/day, no Indirect Handprint (because only adverse environmental impacts), and different Relative Handprint values (Table 2). For the latter, the values represent the effects of replacing SSB with milk. It shows that (for the IU) there is a Direct Relative Handprint (net) of +5.2 μDALY/person/day. Meanwhile, because the SSB has a lower adverse effect (footprint) on UAS than milk, and the final result is negative (−0.5 μDALY/person/day), it cannot be called Indirect Relative Handprint (net or adverse). As all values in Table 2 are in the same unit, it is even possible to aggregate them into an "Overall Relative Handprint" value, which in this case would be equal to +4.7 μDALY/person/day (4.7 = 5.2 + (− 0.5)).

4. Conclusions and outlook

Based on the existing structure from LC(S)A regarding how the flows from a product system can cause impacts, a framework to distinguish what is causing the benefits (product functionality flows or intervention flows) and who is benefiting from them (IU or UAS) was created. Based on this framework, different types of handprint were proposed, which may be used at different scales, i.e., with a simplified terminology that distinguishes it in three types (direct, indirect and relative handprints) or with more specific terminologies (e.g., indirect relative handprint (adverse)), which may even include additional adjectives (e.g., climate). The proposal can be implemented into any type of product system: in this article it was demonstrated in a case study from the food sector.

With this proposal, a first step to consistently use the handprint concept into LC(S)A is achieved, by supporting the communication based on a structured framework for terminology. Moreover, one may challenge the LC(S)A scientific community to further develop methods and approaches and increase the application of the handprint concept into case studies. Some of these challenges may include: (i) development of quantitative methods for partial direct/indirect handprints, in footprint-consistent units; (ii) quantification of all relevant flows, especially the non-physical ones; (iii) development of aggregation techniques (including normalization factors) to allow the calculation of net direct/indirect handprints; (iv) elaboration of PCRs for handprint (e.g., indicating which benefits and adverse effects should not be excluded from the study); and (v) the application of the handprint concept to several case studies, especially those outside of health and food sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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R.A.F. Alvarenga: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing. **S. Huysveld:** Conceptualization, Methodology, Formal analysis, Investigation, Writing - review & editing. **S.E. Taelman:** Conceptualization, Methodology, Formal analysis, Investigation, Writing - review & editing. **S. Sfez:** Conceptualization, Methodology, Formal analysis, Investigation, Writing - review & editing. **N. Préat:** Conceptualization, Methodology, Formal analysis, Investigation, Writing - review & editing. **M. Cooreman-Algoed:** Conceptualization, Methodology, Formal analysis, Investigation, Writing - review & editing. **D. Sanjuan-Delmás:** Conceptualization, Methodology, Formal analysis, Investigation, Writing - review & editing. **J. Dewulf:** Conceptualization, Methodology, Formal analysis, Investigation, Writing - review & editing, Supervision.

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Appendix A. Supplementary data

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Nomenclature List

Parameter	Definition
$B_{P,IU}$	Beneficial effects from product's functionality to the intended user
$A_{P,IU}$	Adverse effects from product's functionality to the intended user
$N_{P,IU}$	Net effects from product's functionality to the intended user
$B_{I,IU}$	Beneficial effects from intervention flows to the intended user
$A_{I,IU}$	Adverse effects from intervention flows to the intended user
$N_{I,IU}$	Net effects from intervention flows to the intended user
$B_{P,UAS}$	Beneficial effects from product's functionality to unintended affected subjects
$A_{P,UAS}$	Adverse effects from product's functionality to unintended affected subjects
$N_{P,UAS}$	Net effects from product's functionality to unintended affected subjects
$B_{I,UAS}$	Beneficial effects from intervention flows to unintended affected subjects
$A_{I,UAS}$	Adverse effects from intervention flows to unintended affected subjects
$N_{I,UAS}$	Net effects from intervention flows to unintended affected subjects
$\Delta B_{P,IU}$	Difference between the absolute value of the product compared to a reference product, regarding the beneficial effects from product's functionality to the intended user
$\Delta A_{P,IU}$	Difference between the absolute value of the product compared to a reference product, regarding the adverse effects from product's functionality to the intended user
$\Delta N_{P,IU}$	Difference between the absolute value of the product compared to a reference product, regarding the net effects from product's functionality to the intended user
$\Delta B_{I,IU}$	Difference between the absolute value of the product compared to a reference product, regarding the beneficial effects from intervention flows to the intended user
$\Delta A_{I,IU}$	Difference between the absolute value of the product compared to a reference product, regarding the adverse effects from intervention flows to the intended user
$\Delta N_{I,IU}$	Difference between the absolute value of the product compared to a reference product, regarding the net effects from intervention flows to the intended user
$\Delta B_{P,UAS}$	Difference between the absolute value of the product compared to a reference product, regarding the beneficial effects from product's functionality to unintended affected subjects
$\Delta A_{P,UAS}$	Difference between the absolute value of the product compared to a reference product, regarding the adverse effects from product's functionality to unintended affected subjects
$\Delta N_{P,UAS}$	Difference between the absolute value of the product compared to a reference product, regarding the net effects from product's functionality to unintended affected subjects
$\Delta B_{I,UAS}$	Difference between the absolute value of the product compared to a reference product, regarding the beneficial effects from intervention flows to unintended affected subjects
$\Delta A_{I,UAS}$	Difference between the absolute value of the product compared to a reference product, regarding the adverse effects from intervention flows to unintended affected subjects
$\Delta N_{I,UAS}$	Difference between the absolute value of the product compared to a reference product, regarding the net effects from intervention flows to unintended affected subjects

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