Title of the Paper: Calculation Of Excess Impact Deduction for Products and Services under IMACS

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Together with the personal sustainable absorption (PSA) calculation method, the XID calculation method allows the calculation of the required conservation to neutralize damaging environmental impacts for each product or service. While these conservations are increasingly applied, their cost will create incentives to prevent damaging impacts, over time leading to adequate protection and restoration of all environmental systems.

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Calculation Of Excess Impact Deduction for Products and Services under IMACS

1. Abstract

The first universally standardized and first-principal-based system of methods was developed to calculate the environmental (E) and human condition (H) impacts embodied by products and services where EH-impacts originating from employee labor are added to other production process EH-impacts *(1, 2).* While the addition of employee labor EH-impacts is essential to correctly calculate the EH-impacts of products and services, this leads to double counting of some of the same EH-impacts under non-sustainable conditions. Without correction this would lead to an incorrect calculation of the EH-impacts for products and services and to supply chain accumulation of E-impacts. An excess impact deduction (XID) calculation method was developed to remove any excess E-impacts and prevent supply chain accumulation. The method applies universally to all products and services.
Together with the personal sustainable absorption (PSA) calculation method *(3),* the XID calculation method allows the calculation of the required conservation to neutralize damaging environmental impacts for each product or service. While these conservations are increasingly applied, their cost will create incentives to prevent damaging impacts, over time leading to adequate protection and restoration of all environmental systems.

2. Introduction

A sustainable lifestyle and sustainable production of goods and services are becoming increasingly important. For products and services, two sustainability measurement systems were developed over the last decades: Product Lifecycle Assessment (P-LCA) *(4)* and environmentally extended input-output life-cycle assessment (EEIO-LCA) *(5).* LCA is widely applied to building products. The limited number of E-impacts currently used could be expanded and it could be applied to all products *(6).* However, LCA methods use historic E-impact averages for their inputs and cannot reflect EH-impact differences in supply routes and distributing organizations. In addition, LCA methods exclude human condition (H) impacts, ignore EH-impacts of the labor used and do not assign costs to damaging EH-impacts, providing little incentive for improvement. The Environmental Impact Measurement And Conservation system (IMACS) was developed to measure the environmental and human condition impacts of products, services and individuals *(1, 2).* The Product Supply Chain Step (PSCS) is used as an integral part of IMACS calculations. Under sustainable conditions all EH-impacts that are inputs to the PSCS end up in the product made or service provided. Under non-sustainable conditions a fraction of the EH-impacts that enter the PSCS with employee labor, move through the PSCS for a 2^{nd} time, leading to double counting of EH-impacts and to supply chain EH-impact accumulation. Excess impact deduction (XID) is needed under non-sustainable conditions to calculate the correct value for the E-impacts of products and services, preventing such supply chain accumulation.

3. Excess Impact Deduction (XID)

Environmental (E) impacts for products and services originate from different sources. These E-impacts van be divided in two groups; E-impacts originating from the location used (land and marine areas and their components) and E-impacts originating from employees producing the product (Employee Labor). In its most simplified form and limited to environmental impacts, a production process can be reduced to figure 1. Location Based E-impacts (LBIs) are the primary inputs to the production process, while the E-impacts of the employees are the secondary inputs. E-inputs from own employee labor and from LBIs directly flowing into the production process are converted to products, to which the E-impacts are assigned until their consumption by end-user consumers.

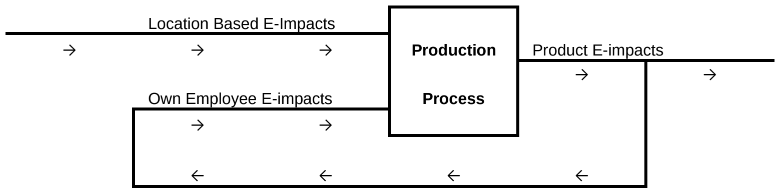

Figure 1: Simplified schematic reflecting environmental E-impacts flowing into and out of a production process where a fraction of the products made are consumed by the employees who made them (recycled).

A fraction of the E-impacts stored in products flow through the production process a 2nd time after their consumption by employees (figure 1). For the typical case, most products made in each specific production process are consumed by the general public and only a very small fraction of each product is consumed by the employees who made them. However, products can be defined small or large. All global products consumed by average global population in a year can be defined as *the global product*. This global product divided by the global population is defined as the *average global product portfolio*. Most individuals work during their lifetimes, allowing us to categorize all individuals as employees. In the latter case, all products and services produced are consumed by all employee/individuals (100% recycle) and flow twice through the production process.

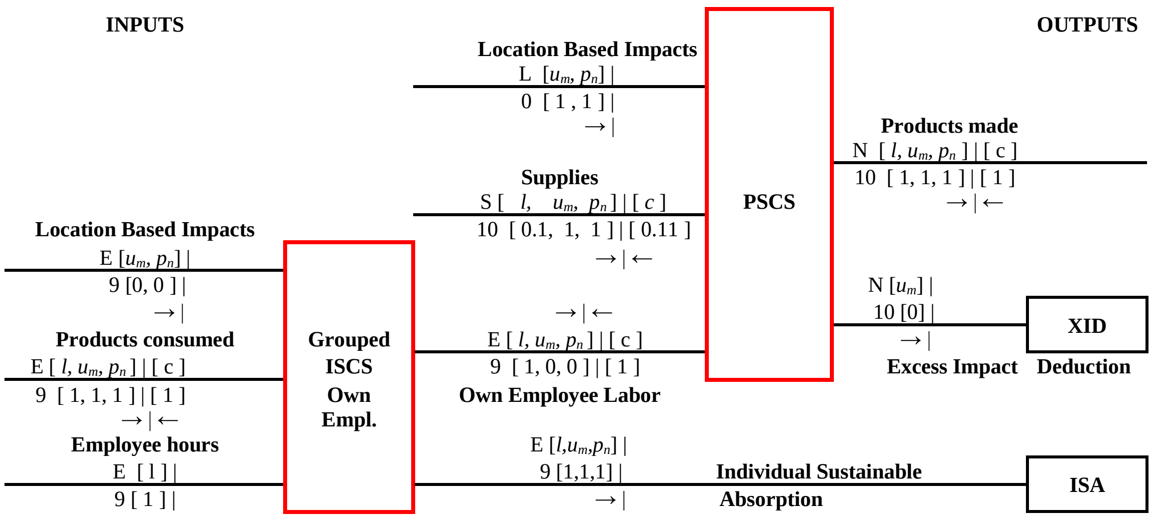

Figure 2a: Combined ISCS-PSCS *(1, 2)* representing one product of an organization and the employee labor used under reference normal conditions (100% sustainable) for a natural resource use variable u_m. A certain amount *(3)* of resource use and conservation applied is absorbed as Individual Sustainable Resource-use Absorption (ISA) and thus removed from the supply chain. The ISCSs of the own employees are grouped in a group-ISCS. Since the ESCSs for suppliers are not shown, the IRA resulting from employees A working for suppliers are not visible in the figure (the total value for E + A = 10). Under reference conditions, the sum of LBI and Supplies is equal to the sum of IRA *(1, 2)*. The product can be a single product or a series of identical products with identical supply chain paths. The product can represent a reference portfolio of products and services as consumed by reference individuals over a year with all multipliers L, S, E and N expressed in Billions *(1,2)*. Conservation is applied by the end-use consumer as required and is a service consumed. The conservation applied is thus included in the product portfolio and is included in the Supplies and LBI.

A production process can be used to manufacture many different products, each using different types and amounts of E-resources and different amounts of labor. Each specific product (or series of identical products) made is represented by a Production Supply Chain Step (PSCS). For most production processes, materials, parts and products (referred to as "Supplies") are purchased as inputs to the PSCS. All E-inputs for which no money is paid or no human work is done are effectively categorized as LBIs. The simple schematic of figure 1 can be expanded to the detail of figure 2a, where the individual consumption (with its in and outputs) is added as the Individual Supply Chain Step (ISCS). Inputs to the ISCS are Products Consumed, LBIs and Human Conditions of which in this stage only the Labor Hours worked and the Salary Paid are included. Sustainable amounts of E-impacts used flow out as Individual Sustainable Absorption (ISA). The inputs to the PSCS can still be grouped as "LBI + Supplies" and "Own Employee Labor". It is the sum of impacts of these two groups that determines the E-impacts of products and services made. As long as this sum is the same, it does not matter whether the E-impacts originate from Own Employee Labor or from Supplies + LBIs. Under reference (100% sustainable) conditions, an individual does not create any environmental damage, the resources used are exactly equal to the allowances, while the required conservations are exactly applied. Under reference conditions, all E-impacts of resources used, damage done and all

E-conservation applied by the individual are deducted from the individual supply chain step (ISCS) inputs as Individual Sustainable Absorption (ISA). The reference individual labor output is free of E-impacts and the labor output is 100% sustainable by definition: [l, u_m, p_n] | [c] = [1, 0, 0] | [1], where l = labor hours worked, u_m = resource use or damage done, p_n =conservation applied and c = salary paid. The values to the right of the equal ("=") sign reflect the values for variables l, u_m, p_n and c and are expressed under normalized conditions *(2).*

Figure 2a, shows a product supply chain step (PSCS) with E-inputs from all own employees and E-impact outputs for products and Excess Impact Deduction (XID). To minimize the use of decimal numbers in later figures, the Location Based Impacts for employees and retail store inputs as set to zero; all E-impacts enter the PSCS with Supplies. Each employee is represented by their own individual supply chain step (ISCS) which for graphical reasons are combined in a "group ISCS". This combination of one PSCS and a group ISCS is referred to as a *combined ISCS-PSCS.* Under reference conditions (100% sustainable) all product portfolios made represent an annual reference portfolio of goods and services as consumed by the reference individual. Looking at the values for N and E in figure 2b (both expressed in billions), N = 10 product portfolios are made, each with l = 1, (representing the work of one reference individual), while the group ISCS represents E = 9 reference employees. This difference is caused by the fact that employees working for suppliers are hidden from view in figure 2a.

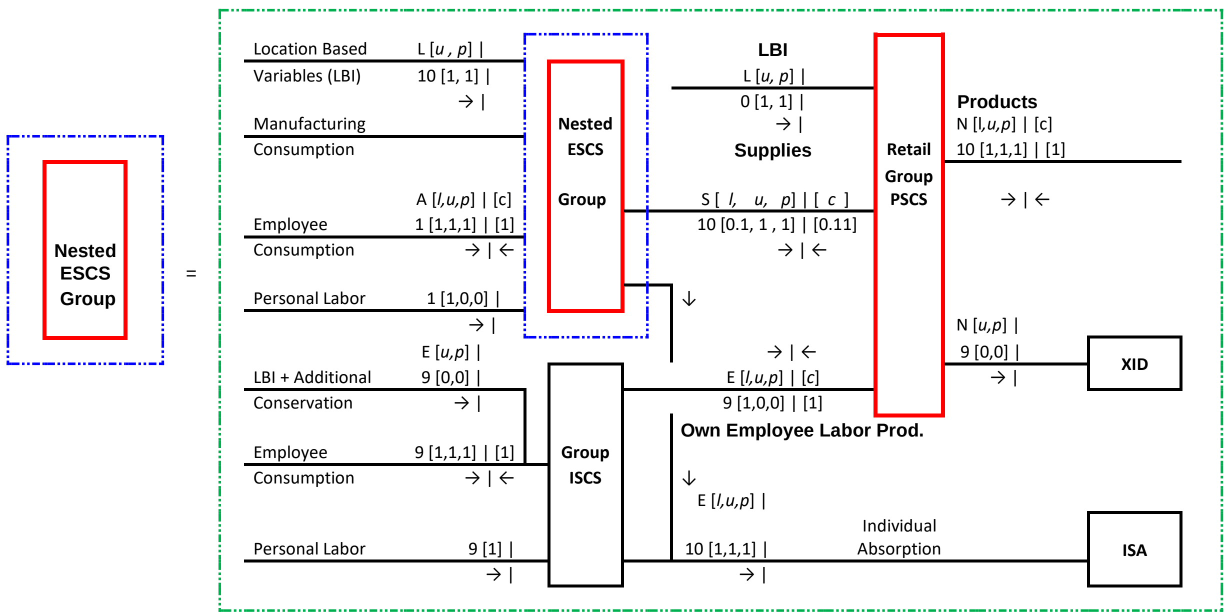

Figure 2b: Combined ISCS-PSCS figure for allowance variables under reference conditions for producers with suppliers and employees, showing the *Nested ESCS Group* repeat unit. The *Nested ESCS Group* repeat unit is indicated by a red outlined rectangle surrounded by a dashed blue outline. The repeat unit shown at the left of the figure represents the larger figure on the right side surrounded by the dashed green outline, which figure on itself contains a *Nested ESCS Group* repeat unit. The product here represents a reference portfolio of products and services as consumed by (say 10 billion) reference individual over a year (with all multipliers L, S, E and N expressed in billions). All products made are used by end-user consumers or used by the *Nested ESCS group* (supplier manufacturing consumption). Multipliers E and A represent respectively the number of "own" employees working for the Retail Group PSCS and the remainder of employees working for the nested *Supplies ESCS Group.* Multipliers L and S respectively represent the number of "*batches*" (expressed as individual reference amounts for u_m and p_n) of respectively LBI and supplies/manufacturing consumption used as inputs to the Nested ESCS Group and Retail Group PSCS. Figure explanations otherwise the same as figure 2a.

A PSCS typically requires supplies from a number of upstream PSCSs, each of which in turn have their own employees and need their own supplies. This represents a case of "nesting" difficult to show in a figure other than using a dedicated "nested ESCS group" as shown in figure 2b. The "nested ESCS group" depiction (shown surrounded by a dashed blue line), represents the same as the depiction in the main part of figure 1b (shown surrounded by the dashed green line). Storage blocks are included as well but are typically not shown *(2).* With all upstream supply chain steps now included in the nested ESCS group, the employees working for upstream suppliers (A = 1) and their IRSA are now also shown.

Supplies represent the E-impacts of all materials, services, energy and employees needed to produce, sell and deliver the supplies to the Retail Group PSCS. In a closed global system, all products made (N = 10) are fully consumed by the employees in the supply chain (E + A = 10). This is better shown in figure 1c, where the implied "recycle" loops are shown. To keep the numbers in the figure simple, the fraction of products recycled to manufacturing is set to zero; all N = 10 products are consumed by the E + A = 10 end-user employees. The figure and calculations also apply when products are recycled to manufacturing (see Methods section). Under reference conditions all supply chain employee labor is E-impact free and all E-impacts thus originate from the sum of LBIs in the supply chain. Under non-sustainable conditions, excess amounts of E-impacts are passed on by individuals (ISCS) to products (PSCS). Under general conditions (sustainable and non-sustainable), all E-impacts enter the supply chain as LBI and exit as ISA + XID. Under reference conditions all E-impacts enter as LBIs and exit the system as ISA (figure 1a). The E-impact balance over the Retail Group PSCS results is zero E-impacts for XID. The same applies to the XID for the PSCS representing Supplies. Note that the Retail Group PSCS is still a PSCS and thus represents a product, not an organization. In this global example case, the product represents 10 billion reference product portfolios (one for every person on Earth).

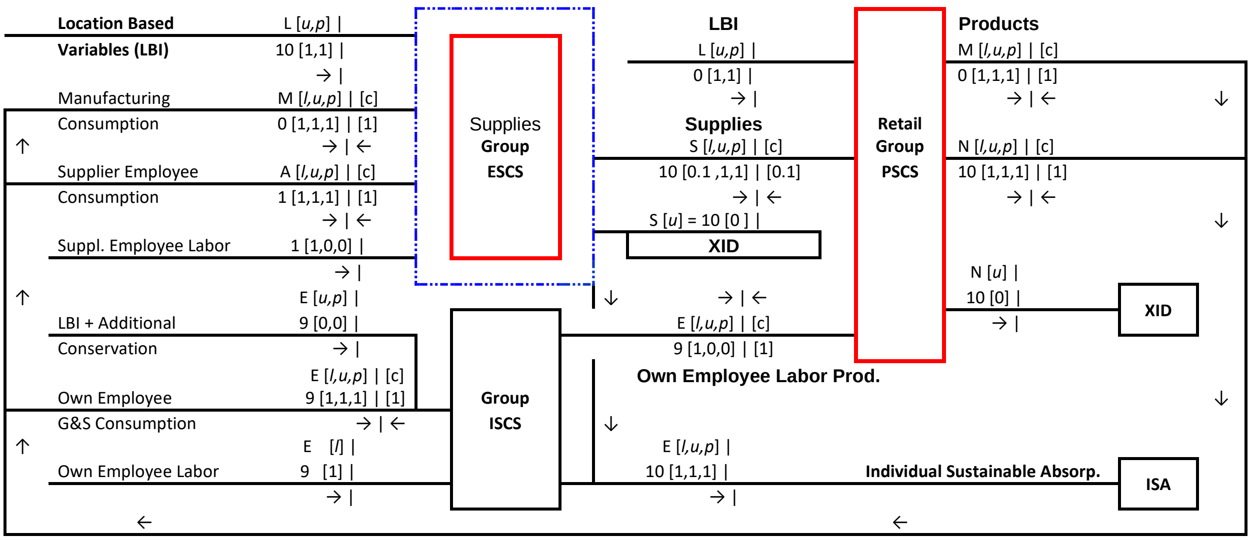

Figure 2c: Combined ISCS-PSCS figure for allowance variables under reference conditions for producers with suppliers and employees, showing the nested group ESCS repeat unit and XID from the Supplies Group ESCS, not shown in figure 2b. Multipliers E and A represent respectively the number of "own" employees working for the Retail Group PSCS and the remainder of employees working for the nested *Supplies Group ESCS*. Multipliers N and M represent respectively products consumed by employees (E + A) and those consumed in manufacturing. Explanations are otherwise the same as for figure 2b.

This zero Excess Impact Deductions (XID) condition changes when all employees throughout the global supply chain increase their consumption to twice the resource use allowance ($u_{m,Empl}$ = 1 changed to $u_{m,Empl}$ = 2). This changed condition is shown in figure 3, where the XID is no longer zero.

In case the XID would be kept at zero, the E-impact balance requirement would create E-impacts for products that are higher for each new cycle than the E-impacts corresponding to employee consumption. This increase is caused by the excessive (non-sustainable) consumption and the limited E-impact amounts that can be removed sustainably as ISA; any excess resource use and all net current damage done not removed as ISA, end up in the labor output and from there in the product. Alternatively, it could also be said that without any correction, E-impacts "accumulate" in the supply chain. In order to prevent E-impact accumulation, for a global supply chain system producing the average portfolio product, the E-impacts for the average product portfolio produced must the identical to the E-impacts of the same product portfolio consumed by end-user consumers. The XID can thus only be calculated exactly from the E-impact balance over the PSCS for the average global portfolio product. This exact value can be used to calculate the values for the parameters used in the formulas describing the "average global portfolio product". The same formulas and parameter values are then used to calculate the E-impacts of all products and services.

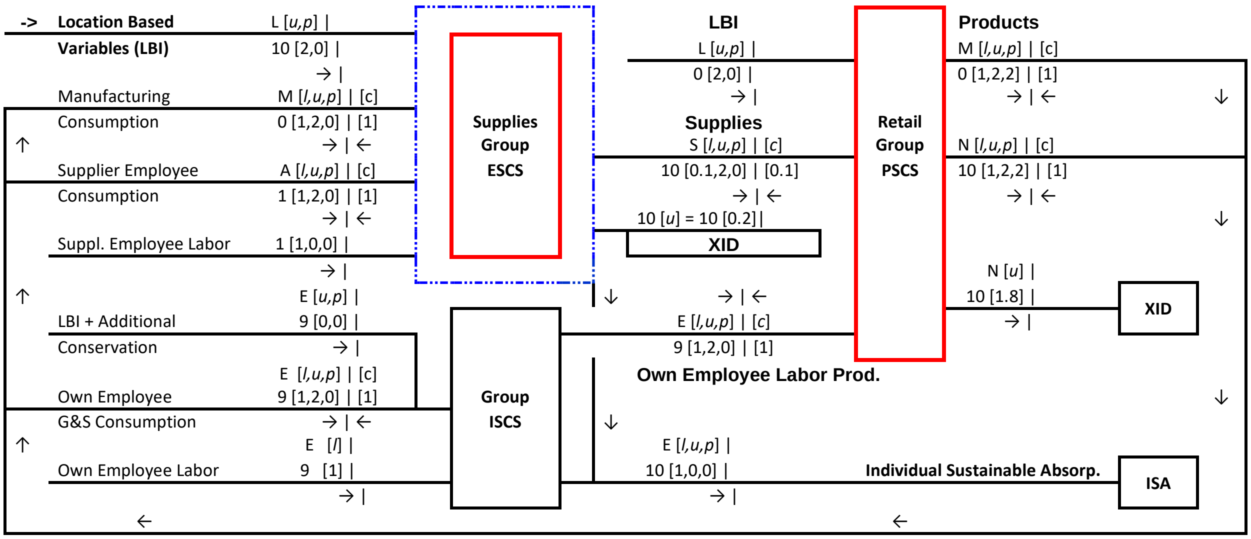

Figure 3: Combined ISCS-PSCS figure for allowance variables for individual consumption equal to twice the allowance and none of the required conservation applied, showing the nested group ESCS repeat unit. The XID of the Supplies Group ESCS is also shown. Multipliers E and A represent respectively the number of "own" employees working for the Retail Group PSCS and the remainder of employees working for the nested *Supplies Group ESCS*. Multipliers N and M represent respectively products consumed by employees (E + A) and those consumed in manufacturing. Explanations otherwise the same as for figure 2c.

Method Type	Benefits	Drawbacks
A. Addition of E-impacts for X and Y and deduction of XID	• Correct method for sustainable conditions. • Benefits organizations with higher-than-average fraction of participating employees buying participating products.	• Continues to create supply chain E-impact accumulation for non-sustainable conditions.
B. Averaging of E-impacts X and Y	• Provides a solution for E-impact supply chain accumulation where averaging method A does not work. • Maintains incentive to lower E-impacts for both employee labor and Supplies + LBI.	• Gives incorrect results (at half the E-impacts) under sustainable conditions. • Calculates too low E-impact for organizations with (close to) sustainable employees and high E-impacts for Supplies + LBI.
C. Averaging of methods A and B using correction factor	• All benefits of methods A and B. • Allows elimination of supply chain accumulation on global and regional scales. • Use of Exponential Average calculation model allows transition from "even" weighted to "highest" impact weighted average, maximizing incentive to improve. • Parameters can be periodically optimized (annually).	None

Table 1: Benefits and drawbacks of methods to calculate E-impacts of goods and services from sum of Supplies and LBI (X) and from employee labor input (Y).

E-impacts of XID and products made can be calculated using different methods; additive (A) and averaging (B). Additive method A is the base case, since it applies (without the need for corrections) to sustainable conditions, where arithmetic averaging would produce the wrong results (half of the correct value).
All resource-use and E-damage impacts first enter the PSCS as LBI or with Supplies and are stored in products not yet consumed. With the consumption of products and services, E-impacts amounts in excess of the sustainable available amounts are transferred to the labor output and from there to the product. The excess resource use present in the labor output in figure 3, thus enters the PSCS for a 2nd time, leading to "double counting" of the same E-impacts. The apparent increase in E-impacts is an artifact of the calculation method and needs to be corrected. For the example shown in figure 3, all employee E-impacts originate from an ISCS and thus from participating employees and are inputs to a PSCS and thus apply to a participating product. Therefore, all labor E-impacts in figure 3 are passing through the PSCS for a 2nd time and need to be deducted as XID to prevent supply chain accumulation. However, especially after first implementation of IMACS, participation rates are very low and most of the XID ends up being close to zero. For non-participating goods and services no PSCS exists and PSCS based E-impacts calculations are not available. Their E-impacts can only be estimated. Such products go through a PSCS as "a first pass". The same applies to E-impacts from labor of non-participating employees. A purchase is only qualified as *participating* when the good or service is sold by a *participating* seller, listed by the seller as

participating and purchased by a *participating* buyer. With participation starting at zero and only gradually increasing over time, almost all products sold by participating buyers just after first implementation are non-participating products. Of all participating products purchased by end-user consumers, most E-impacts are estimated, while accurate E-impact rated data are available for only a small fraction (the PSCS rated products). Only the latter fraction of E-impacts in the labor output would qualify as passing a 2^{nd} time through a PSCS; all other E-impacts represent a 1^{st} pass. Expressed as a percentage of total E-impacts, a participation based XID will be zero at start and remain small during most of the E-restoration period. This in turn means that supply chain accumulation would still take place, requiring other methods to address this. However, the above is based on the average supply chain; organizations that manage to motivate their employees to participate and buy participating products can still see a benefit from a participation based XID resulting in a significantly lower E-impacts for their products and services made.
E-impacts accumulation in the supply chain is caused by double counting of E-impacts that enter the PSCS for a 2^{nd} time with the employee labor output. At its worst this would lead to doubling of the E-impacts of products per consumption cycle and would be the prevalent condition early after EIMCS implementation when almost no E-impact reductions have materialized. Under those conditions, averaging would completely undo any such "doubling" of E-impacts, but would produce product impacts of half the correct value under sustainable conditions (i.e. for sustainable employee labor).
For the example used in figure 3, the E-impacts from labor are almost the same as the combined impacts from Supplies and LBI. This is typical for E-Impacts for all E-resource use and all E-Damage done. A good approximation of the product E-impacts can thus be calculated as the average of E-impacts of Labor and the combined Supply and LBIs.

4. Results and Discussion

A specific method must be followed to include E-impacts from employees, supplies and location-based impacts in the calculation of E-impacts for products and services, while preventing supply chain E-impact accumulation.
The E-impacts of products and services can be calculated as the exponential average of methods A and B and application of a correction factor: $u_{m,C,Product} = f_{Correction} * \text{ Exponential Average } (u_{m,A,Product} , u_{m,B,Product})$

with: $u_{m,A,Product} = u_{m,X} + u_{m,Y} - u_{m,XID,Participation}$ *(12)*

with: $u_{m,B,Product} = (u_{m,X} , u_{m,Y}) / 2$

where $u_{m,C,Product}$ = normalized E-impact u_m for product or service calculated using method C
where $u_{m,A,Product}$ = normalized E-impact u_m for product or service calculated using method A
where $u_{m,B,Product}$ = normalized E-impact u_m for product or service calculated using method B
where $u_{m,X}$ = normalized E-impacts u_m of Supplies and LBI (X)
where $u_{m,Y}$ = normalized E-impacts u_m of Employee Labor (Y)
where $u_{m,XID,Part.}$ = normalized Excess impact deduction calculated based on participation for u_m
where $f_{Correction}$ = correction factor to scale E-impacts of production to consumption
where Exponential Average (A, B) = $\overline{u}_{m,ew} = \frac{A^{(Q+1)}+B^{(Q+1)}}{Y^{Q}+Z^{Q}}$

For method B, I want to give equal weight to the inputs for calculation of the average. The arithmetic average assigns equal weights to $u_{m,X}$ and $u_{m,Y}$ and is therefore the best type of average for method B. For method C, the arithmetic average is best at the initial low rates of participation, since it gives equal weight to methods A and B. However, at 100% participation rates, but otherwise non-sustainable labor conditions, the arithmetic average for method A would exclude all E-impacts from employee labor ($u_{m,A,Product} = u_{m,X}$) and calculate E-impacts of the global product portfolio at half the correct value. Under 100% participation conditions the exponential average using an exponent value of unity (Q = 1) for method C would return the larger of the two values and would under those conditions reflect the correct outcome. For an exponent value of zero (Q = 0) the exponential average is equivalent to the arithmetical average (see Methods). For method C, a gradually increase for exponent Q, starting at Q = 0 for zero % participation to Q = 1 at 100% participation, would meet the start and end conditions. A linear increase of Q = 0 to Q = 1 between 0% and 100% participation is the simplest option.
While method C produces E-impacts outcomes on a global level that best incorporate the various drivers maximizing future sustainability, the values produced are not yet correct. The total of E-impacts of products and services produced ($u_{m,Produced}$) over a long period needs to be equal to the total E-impacts of products and services

consumed ($u_{m,Consumed}$) by humanity over the same period. The correction factor $f_{Correction}$ is needed to scale the calculated average production E-impacts to the correct consumption value.
To illustrate the use of the method, a calculation model is used where the global individual and product participation rates are linearly increased over a 25-year period from 0% to 100%, while the E-impacts of the global production are linearly reduced from 100% in year zero to 0% in year 25. Note that while such E-impact reduction due to increases in participation are possible using the IMACS system, such reductions depend of the successful implementation of many other components of the IMAC system that are not addressed in this article. The calculation model assumes this inverse relation to exist with the mere purpose to calculate the correction factor as a function of participation.

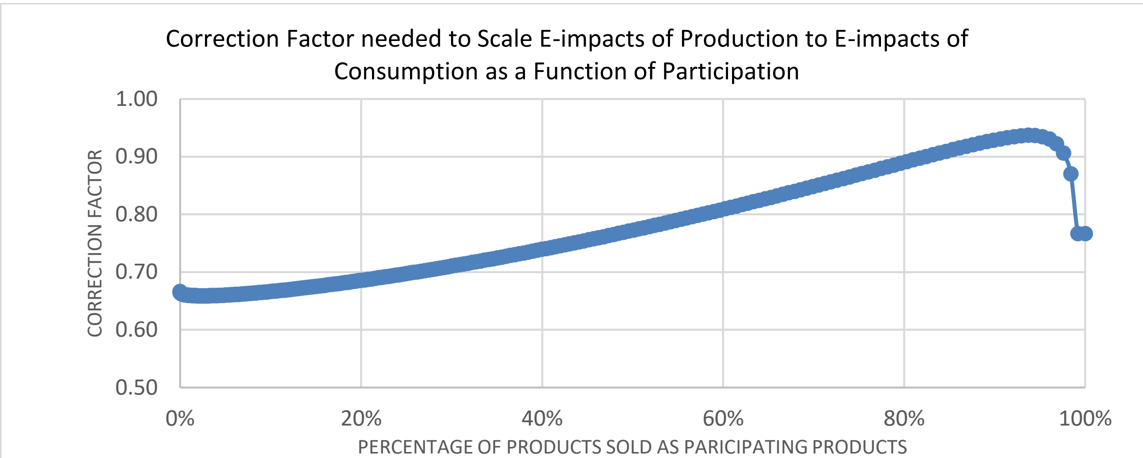

Figure 4: Correction factor needed to scale E-impacts of production to E-impacts of consumption as a function of product participation *(7).*

The correction factor $f_{Correction}$ is a function of the rates of increase of individual participation and product participation, the rates of E-impact reduction and the recalculation interval. The correction factor needs to be recalculated periodically (monthly, weekly) for the global collection of all participating products and services sold. Under the above-described model conditions, the correction factor remains the same independent of the starting E-impact values for production and consumption. While calculated for the sum of all globally participating products and services, the same value for $f_{Correction}$ is applied globally to each and every product or service at any given time.

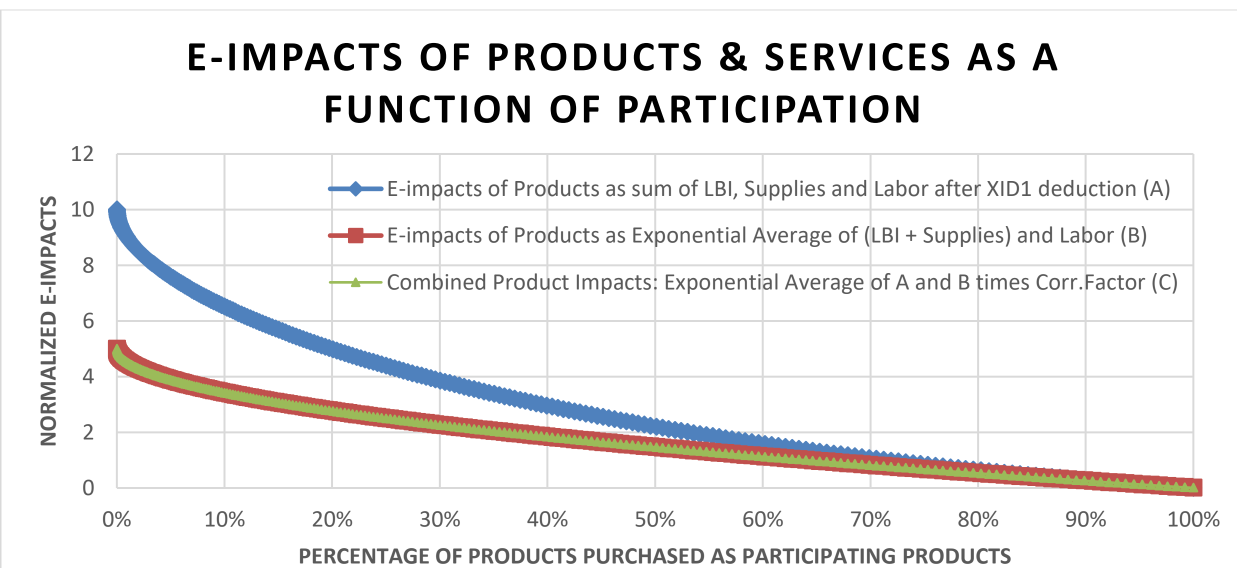

Figure 5: E-impacts calculated for a global product portfolio. Blue, red and green data represent results for respectively method A, B and C. Variable values correspond to those listed in table 1 *(8).*

End-use consumers who participate in the IMACS ("participating individuals") and buy products that are assigned by the sellers to participate ("participating products") have lower E-impacts. How this mechanism works will be explained in later publications. Model results are shown in figure 4, where the calculated E-impacts are plotted against the percentage of products sold as participating products. Using the average based method B, the E-impacts of the global product portfolio show a gradual reduction to zero. Product E-impact results for calculation model A (in blue) are initially twice as high as for methods B (in red). Initially, the participation is zero, resulting in a zero participation-based XID ($XID_{Participation}$). At the end of the model period, all products are sold as participating products and the $XID_{Participation}$ is equal to the labor E-impact. This limits the net product E-impacts for method A to the sum of Supplies and LBI.
Using the global correction factor $f_{Correction}$, the product E-impact (overall method C) for 100% individual and 100% product participation are calculated for years 1, 5, 10, 15, 20 and 24 and compared with the model values using the lower model participation rates for the corresponding years. For years 1, 5 and 10, a 34 to 32% reduction in E-impacts results from full participation compared to the lower participation in the model for those years.
Organizations that participate early and manage to motivate their employees to participate and buy participating products where available, can strongly reduce the E-impacts of the products and services they produce. This strongly reduces the costs of E-vouchers they need to buy. This excludes the E-impact lowering effects of participating products and services bought by participating employees compared to their non-participating equivalents. (See figures 6 and 7). The overall cost savings effects are thus larger than the above 32 to 34% of E-voucher costs.

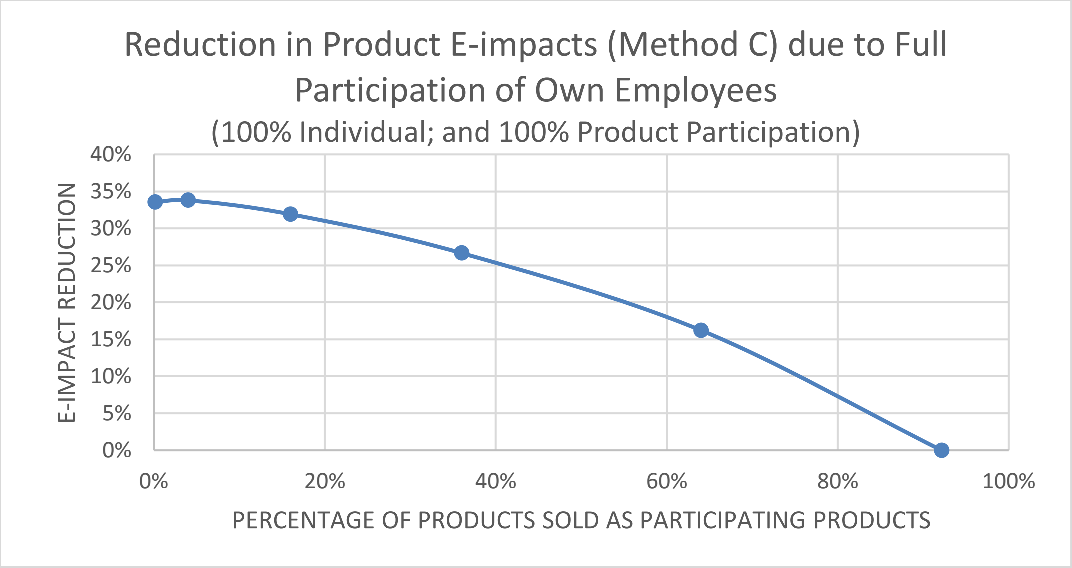

Figure 6: Reduction of E-impacts of products and services of organization due to 100% employee and 100% product participation as function of global model percentage of products sold as participating product *(8).*

The method provided allows calculation of E-impacts of products and services while preventing supply chain accumulation along the entire path to global environmental restoration, not possible without this method.
This in turn allows the calculation for each product or service of the required conservation to neutralize damaging environmental impacts. While these conservations are increasingly applied, their cost will create incentives to prevent E-damage, over time leading to adequate protection and restoration of all environmental systems.

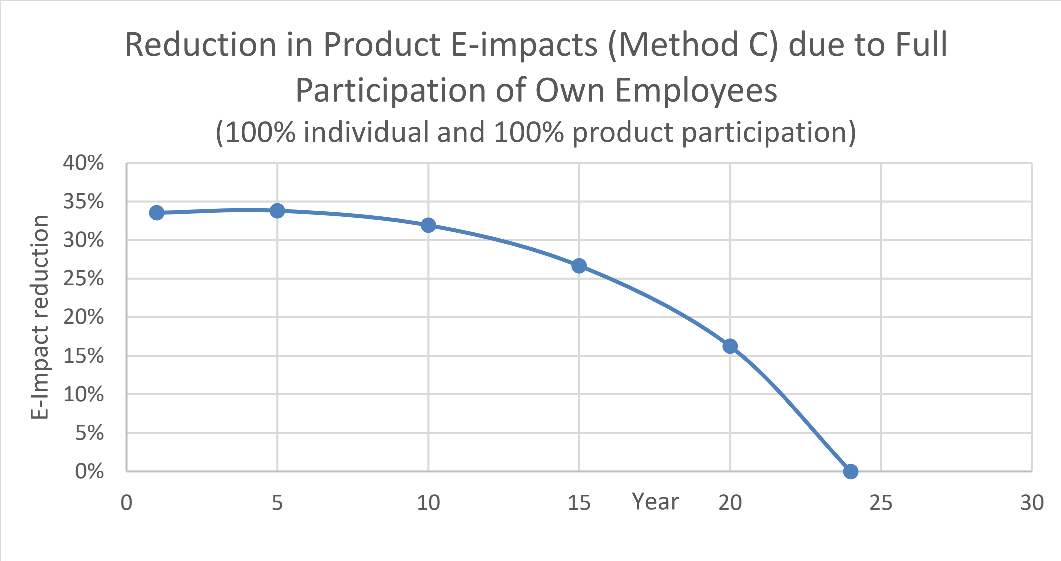

Figure 7: Reduction of E-impacts of products and services of organization due to 100% employee and 100% product participation as function of time (In year 25 all products are sold as participating products) *(8).*

5. Methods

5.1. Global Supply Chain and XID

5.1.1. Global Supply Chain under Reference Conditions

The IMAC system is based on environ-humane (EH) impact balance calculations over environ-humane supply chain steps (ESCSs) *(1, 2).* Goods and services are treated as merely packaged forms of EH-impacts. While physical products can be stored on shelves and store such EH impacts for a long time, services and labor provided transfer such EH impact immediately on delivery. For each individual the EH impacts reflecting the labor provided are calculated using a unique Individual Supply Chain Step (ISCS) *(3).* For each product or series of products with an identical supply chain path, the EH impacts are calculated using a unique Product Supply Chain Step (PSCS) *(1, 2).* The combined ISCS-PSCS is shown in figure 1a. The collection of global ESCSs form a closed system, where all EH impacts enter as individual labor hours and location-based impacts (LBIs) and exit as personal sustainable absorption (PSA) *(3)* and excess EH impacts deduction (XID) (see figures 1b and 2b). Individual labor hours and LBIs can be measured/calculated accurately and (using these inputs) the PSA can be exactly calculated. The XID is the catchall for E-impacts that passed through a PSCS for a 2nd time or that would otherwise lead to supply chain accumulation of E-impacts. For industrial societies, most LBIs enter the ISCS-PSCS as an input to the product supply chain step (LBI_{PSCS}), while a small fraction enters as an input to the individual supply chain step (LBI_{ISCS}). Per definition, under reference conditions, the annual product portfolio consumed by the reference individual (the reference product portfolio), is 100% sustainable. Under reference conditions, the labor output is free of (net) EH impacts and all EH impacts enter the combined ISCS-PSCS with Supplies and LBIs (see figure 1). A PSCS typically requires supplies from a number of upstream PSCSs, each of which in turn have their own employees and need their own supplies. This represents a case of “nesting” difficult to show in a figure other than using a dedicated “nested ESCS group” as shown in figure 1b. The “nested ESCS group” depiction (shown surrounded by a dashed blue line), represents the same as the depiction in the main part of figure 1b (shown surrounded by the dashed green line). Storage blocks are included in the “nested ESCS group” but are typically not shown.

In order to understand how to calculate the XID, the global system of ESCSs needs to be evaluated. On a global scale all products produced are ultimately consumed by the world’s human population. Products wasted and all EH impacts otherwise ending up as waste are considered EH impacts “consumed” by individuals. To better visualize this, we divide the world in three groups of ESCS and fold all ESCS for each group into a single ESCS of its kind.

Three group ESCSs can thus be created:

- All products and services sold directly to end-user consumers (Retail Group PSCS)
- All suppliers supplying retailers (Suppliers Group ESCS)
- All employees working directly for retailers (Retail Group ISCS)

The assumption is made that the entire world participates in the IMACS system and all products consumed are PSCS rated products. These three groups of ESCSs are visualized in figure 1c.

Each product manufactured in figure 1c represents the global annual portfolio consumed by the average global citizen. While all EH-impact variables [L, U_m, P_n,] | [C] are expressed in their original form with units while traveling through the supply chain, calculation of the ISA and XID requires the normalized *(1, 2, 3)* and unit-less version of the original variables [*l*, u_m, p_n] | [$_c$]. I will start with noting that there is a potential for supply chain accumulation of E-impacts for use & damage variable *u*, (where *u* stands for any of *m* variables u_m) and I will explain later why this is not an issue for any of the other EH impact variables *l*, p_n and c (where *l* = labor hours, p_n = conservation applied, *c* = salary or price paid). Supply chain accumulation is thus limited to environmental impacts (E-impacts).
Looking at the global EH impact balance, all environmental impacts enter as location-based impacts (LBI), while all humane impacts enter with the humane condition input, for which currently only the labor hours *l* are represented. Since the LBI inputs to ISCS and retail PSCSs are very small compared to the LBI inputs to the Supplies group ESCSs, the former LBI inputs are set to zero. All global E-impacts can only flow out as personal sustainable absorption (PSA) and excess impact deduction (XID). The global EH impact balance for variable *u* is:

$$\text{IN} = \text{OUT}$$
$$u_{LBI\_SG\_ESCS} + u_{LBI\_RG\_PSCS} + u_{LBI\_RG\_ISCS} = u_{PSA} + u_{XID}$$

with $u_{LBI\_SG\_ESCS}$ = normalized impacts variable for use and damage variable *u* for LBI inputs to the supplies group ESCS
with $u_{LBI\_RG\_PSCS}$ = normalized impacts variable for use and damage variable *u* for LBI inputs to the retail group PSCS
with $u_{LBI\_RG\_ISCS}$ = normalized impacts variable for use and damage variable *u* for LBI inputs to the retail group ISCS
with u_{PSA} = normalized impacts variable for use and damage variable *u* for PSA outputs of the retail group ISCS
with u_{XID} = normalized impacts variable for use and damage variable *u* for XID outputs of the retail group PSCS

Under the global "recycle" conditions shown in figures 1c and 2, all net E-impacts originate from Supplies and LBIs that are inputs to supplier ESCS and retail PSCS groups. Since this is a global balance, the entire global production is consumed as individual consumption by the global population. Under reference conditions all E-impacts are absorbed as PSRA and the labor input to the PSCS is free of E-impacts (Figure 1c). The E-impact balance over the Retail Group PSCS and the Supplies Group PSCS closes for all E-impacts without the need for any XID deduction for use & damage variables ($u_{LBI\_SG\_ESCS} = u_{PSA}$ and $u_{XID} = 0$).

5.1.2. Global Supply Chain under Non-Sustainable Conditions

For non-sustainable conditions (i.e. individual natural resource use of twice the allowance) as shown in figure 2, the labor input to the product supply chain step (PSCS) does carry E-impacts. This is the case since E-impacts of goods and services in excess of allowances are not absorbed as PSA. With LBI inputs to the ISCS assumed to be zero, these E-impacts inputs to the PSCS represent a 2nd pass of the same E-impacts that were earlier recorded entering the group PSCS. In the overall global balance, with increasing E-impacts entering as LBI inputs to supplies and ISA limited to the allowance, E-impact carried by the labor output cannot leave the supply chain except as XID. The same applies to current damage variables for which less than required conservation is applied.
Focusing on variable *u* as an allowance variable, without any outflow as excess E-impact deduction (XID), the sum of inputs to the PSCS would increase the value of *u* in the product $u_{Product}$ with every production-consumption cycle. If left uncorrected, this would lead to E-impact accumulation in the inventory of supply chain products ("*supply chain accumulation*"), leading to increasingly higher calculated E-impacts for goods, services and individual labor output. To correct this issue, E-impacts passing for the 2nd time through the PSCS must be removed by routing these to an (XID) block.
Figures 1b and 2 show a closed E-impact balance for allowance variables. A total of M + N portfolio products are made, of which M are consumed as supplies in manufacturing and N are consumed by employees. Any fraction of production recycled to manufacturing increases the internal flows of E-impacts but does not affect the net individual

consumption or the XID required. For simplicity of further evaluations, M is set to zero. Since figures 1c and 2 reflects a global situation, all multipliers can be interpreted as representing billions.

Excess E-impact accumulation is not an issue for any of the other EH-impact variables *l*, p_n and c. Starting with conservation variable p_n , conservation cannot accumulate in the supply chain due to shortage of conservation throughout the entire environmental restoration period. Access to conservation affects individual sustainability, career options, income and (hopefully) future taxation. For reasons of fairness, access to conservation needs to be rationed and not enough conservation will be available to offset sustainable requirements for goods and services purchased. Even in case a lower income individual uses less than the available allowance, any conservation applied in excess of requirements will end up in the labor input. Any such excess conservation will be assigned to a product made and ends up consumed in the next consumption cycle, removing such excess.
The variable for labor hours worked *l*, is an allowance variable, for which the allowance is set slightly higher than or equal to the average number of labor hours worked and may be regionally adjusted. Consequently, on average all labor hours entering with employee labor exit with personal sustainable resource use absorption (PSA) and (except for some regional effects) no significant accumulation is likely to occur.
Compensation variable *c* moves in compensation direction, independently of environmental impacts. All income paid is on average used for the purchase of goods and services. While income will accumulate with a limited number of very wealthy individuals (as it does today), money does not accumulate in products produced and services provided and no supply chain accumulation will take place.
The above section shows that E-impacts will accumulate in the supply chain if no corrections are made.
The objectives for a method to calculate product use & damage variables impacts are (in importance order):

1. Create a strong incentive for sustainability improvements for all participants.
2. Prevent supply chain accumulation of use & damage impacts variables.
3. Calculate the most accurate use & damage variable impacts for products.

5.1.3. Recycling to Manufacturing and Effects on XID

In paragraph 5.1 it was shown that under global reference conditions, the environmental use and damage impacts collected during manufacturing of goods and services end up in the product without any need for correction as excess impact deduction (XID). Under global reference conditions, the location-based impacts (LBIs) and supplies that are inputs to the retail group PSCS, add up to the impacts reflecting sustainable product values. Once these sustainable products are consumed by the average global consumers, the resulting labor is sustainable, implying zero net E-impacts. While this labor provides an input to the retail group PSCS, the absence of any net E-impacts does not increase the E-impacts of the products made. The XID, as the result of the EH balance over the retail group PSCS, is thus calculated to be zero.

How does this change when a fraction of retail products is recycled to and consumed in manufacturing?
(Consumed by manufacturing processes, not consumed by individuals.)
When drawn in figures, E-impacts of materials and supplies feed from one PSCS into the next and add up along the supply chain. Without any labor inputs, the PSCS product output is correctly calculated by adding all PSCS inputs, without any need for XID correction. This principal continues to apply independently of how the PSCS diagram is drawn (as a straightforward feed or as a recycle stream). Any products that are outputs of the retail PSCS and later used as inputs to other PSCSs should be treated as materials and products temporarily stored and later used as inputs as for any other products. In principle, the labor output needs to be an input to the PSCS, since labor can be a major source of E-impacts not yet accounted for (LBIs and not E-impact rated goods and services). Therefore, the labor source of E-impacts needs to be an input to the PSCS as any other E-impacts originating from LBI and supplies that are direct inputs to PSCS.

This then leads to the question: "*Why, under non-sustainable conditions, does "recycling" of product E-impacts to end-user consumers lead to supply chain accumulation (requiring an XID correction) while recycling of the same product E-impacts to manufacturing does not?"*
The answer is that only individual end-user consumers truly consume E-impacts. E-impacts accumulated by products are essentially "stored with the product" but not yet consumed by individuals, while E-impacts of products purchased by individuals are considered consumed. After consumption by individuals, all E-impacts present in the labor output represent "excess E-impacts" in case the same E-impacts already passed through a PSCS. The total of

E-impacts in the labor output can be divided in two parts; the part that did not yet pass through a PSCS (the 1st pass E-impacts) and the part that did. The latter part represents the 2nd pass amount and needs to be deducted as XID to prevent supply chain accumulation of E-impacts.

5.1.4. 1st and 2nd Pass; How Do They Compare?

E-impacts for a participating product or service need to be determined using a product supply chain step (PSCS) or Rating Supply Chain Step (RSCS) calculation. E-impact can flow via two routes to a product or service:

a) As inputs originating from Supplies and LBIs (Location Based Impacts) used for the product
b) As inputs originating from labor outputs from own employees making the product

E-impacts can originate:

- Only from a)
- Only from b)
- From both a) and b)

In all current cases E-impacts originate from both a) and b). For Current Damage E-impacts, there are two extreme theoretical possibilities. The 1st one is that E-impacts originate form Supplies and LBIs, while the Labor used is E-impact free. In this case the sum of E-impacts from Supplies and LBIs is used to calculate the E-impacts of the product. The 2nd is that all E-impacts from Supplies and Labor are zero, while all Supplies and LBI are free of current damage E-impacts. In that case the sum of E-impacts from Labor is used to calculate the E-impacts of the product.
In case E-impacts originate from a) and b), a determination needs to be made as to which E-impacts in the labor output passed through a PSCS for the 2nd time and this latter amount must be deducted as XID. It is still possible that all E-impacts in the Labor output are "new" and never passed through any PSCS and thus represent a 1st pass through the PSCS. In the latter case all E-impacts are added while no XID applies.

5.1.5. XID and Variable Type

For E-impact accumulation to occur, the same E-impact amount needs to pass through a product supply chain step (PSCS) for a 2nd time. Typically, these are different PSCSs. For example; CO_2 emissions made to bake a bread are assigned to each of the series of 1,000 breads of the specific type made in bakery A that day and thus passed through the PSCS representing the bread (1st pass). Car mechanic B eats the bread and transfers the CO_2 emissions to his employer C. Employer's C software assigns the CO_2 emissions to a car repair job (a service), done by mechanic B represented by a PSCS (2nd pass). The latter is not the case for unrated products and services (if the bread was a non-participating product) for which the impacts never passed through a PSCS.
However, in case the bread was sold as a participating product, this 2nd pass through a PSCS does not take place if sufficient E-conservation is available to sequester and neutralize the CO2, since the automatically applied E-conservation immediately following the primary purchase, would prevent any transfer to the labor output of employee B.
Therefore, E-impacts that passed through a 1st PSCS need to meet one of two conditions to pass a 2nd PSCS:

A. Insufficient conservation is available to meet the end-user consumer conservation requirements
B. The conservation applied is limited to the allowance

Condition A initially exists for all conservation types and is likely to continue for most types throughout the period of global environmental restoration. It serves no function to assign sequestered CO_2 to historic CO_2 emissions stored in the atmosphere (reducing the atmospheric CO_2 inventory), instead of assigning the same amount of sequestered CO_2 to offset current CO_2 emissions (reducing the increase of the atmospheric CO_2 inventory). The same applies to all other types of historic damage. Any restoration applied to historic damage, would therefore need to wait until the restoration capacity for the specific type of conservation exceeds the requirements to offset the current damage for the corresponding variable. The IMACS organization can do this by initially setting the annual fraction of historic damage per dollar spending that is assigned to goods and services to a value low enough to meet global conservation requirements and only gradually increasing this fraction to match conservation capacity. A faster rate of growth of conservation capacity would quicken the return to pre-industrial environmental conditions and vice versa.

If such a control mechanism based on conservation capacity can be applied to historic damage, it could theoretically also be applied to current damage variables. Under such controlled conditions, all current damage done would be reduced by a “conservation availability factor”. No current damage E-impacts would end up in the labor output and no accumulation would occur for current E-damage variables. However, there are problems with this approach. Individual E-sustainability values are calculated fully or partially from labor output E-impact values. In case the E-impacts are reduced to zero, E-damage done would no longer show in the labor output, making the calculation of individual sustainability values impossible. In addition, E-damage done would no longer transfer to the PSCS, even when the damage would represent a first pass. For these reasons, a conservation capacity control mechanism cannot be applied to current damage or allowance variables.

For allowance variables, the amounts of resources used and conservation applied that must be removed from the supply chain is calculated as *(3)*:

$$u_{m,ISRA} = p_{n,ISRA} = \text{MIN}(1, u_{m,All,Cons}, p_{n,All,Cons})$$

where $u_{m,ISRA}$ = the E-resource amount removed as Individual Sustainable Resource-use Absorption (ISRA)
where $p_{n,ISRA}$ = the E-conservation amount removed as Individual Sustainable Resource-use Absorption (ISRA)
where $u_{m,All,Cons}$ = the E-resource-use amounts consumed by the individual
where $p_{n,All,Cons}$ = the E-conservation amount applied by the individual (part of individual consumption).

In the above equation, the numeric value of unity represents the normalized allowance value. Even when sufficient E-conservation is available to meet the requirements for participants, this still limits both the resource-use amount and the conservation that can be removed as ISA to the allowance amount, with the balance ending up in the labor output. It is clear that allowance variables can accumulate in the supply chain. While all excess impact deductions (XID) are generically referred to as XID, this name varies with variable type. For allowance variables the XID is referred to as excess natural resource use deduction or XNRD. For current damage variables, the excess XID is referred to as XNRD.

5.2. Calculation of E-impacts for Products Using XID

5.2.1. General Method A, using Excess Impact Deduction (XID)

The excess impact deduction $u_{m,\ XERD}$ deducted in the XID block in figure 3 can be calculated in two ways:

- based on individual and product participation ($u_{m,\ XERD,\ Participation}$)
- as the E-impact balance over the PSCS ($u_{m,\ XERD,\ Balance}$) after calculation of the product E-impacts $u_{m,Product}$.

Figures 1c and 2 show two different IMACS participating worlds. Figure 1c reflects a world of only reference individuals, with zero excess resource use and damage in the labor output and zero XID. Figure 2 reflects a non-sustainable world with natural resource use representing twice the allowance. While in figure 2 all required conservation is applied, all resource use exceeding the allowance ends up in the labor product. The XID required to prevent supply chain E-impact accumulation is now positive ($u_{m,\ XERD} = 0.9$) and would be twice as high if no conservation was applied. One way to prevent supply chain accumulation of E-impacts is to deduct any E-impacts that are inputs to a product supply chain step, if this impact was added (and counted) a 1st time as an input to another PSCS. XID only applies to PSCS inputs that would represent a 2nd pass of an E-impact already counted during a 1st pass. E-impacts of unrated products consumed were not counted as PSCS and their presence in the labor input to the PSCS would not qualify as a 2nd pass and would not qualify as XID. E-impacts for variable u_m qualifying as XID and the resulting E-impacts for variable u_m for products made, can be expressed without making assumptions for variable types and PSA calculation treatment. For each employee part of the own employee ISCS group, the fraction of resource use that qualifies as XID can be calculated based on employee participation and the fraction of resource use consumed as PSCS rated products:

$$u_{m,Labor.i,XID} = u_{m,Labor.i} * f_{P,i} * f_{m,Rated,i} \quad (1)$$

$$f_{m,Rated,i} = u_{m,Rated,i} / u_{m,Total,i} \quad (2)$$

where $u_{m,Labor,i,XID}$ = resource use for variable u_m in labor output of employee i qualifying as XID
where $u_{m,Labor.i}$ = resource use for variable u_m in labor output for employee i

where $f_{P,i}$ = integer representing IMACS participation for employee i (where 1 = participation)
where $f_{m,Rated,i}$ = fraction of resource use variable *m* for employee i originating from PSCS rated products
where $u_{m,Rated,i}$ = resource use for allowance variable u_m for employee i for PSCS rated products consumed
where $u_{m,Total,i}$ = resource use for allowance variable u_m for employee i for total of all products consumed

The sum (3) applies to the collection of all own employees E:

$$D_{a,Labor,XID} = SUM_i^{\ E} (u_{m,Labor,i,XID}) = E * \overline{u}_{m,Labor,XID} = N * u_{m,XID} \tag{3}$$

where $D_{m,Labor,XID}$ = sum of values of E-impact variable u_m in labor output for all E employees qualifying as XID
where $u_{m,Labor,i,XID}$ = value of E-impact variable u_m qualifying as XID in labor output for employee i
where $\overline{u}_{m,Labor,XID}$ = value of E-impact variable u_m qualifying as XID in labor output for average employee
where $u_{m,XID}$ = value of E-impact variable u_m in PSCS output qualifying as XID
where E = total number of own employees
where N = number of products made

The E-impact balance over the PSCS provides:

$$L * u_{m,LBI,PSCS} + S * u_{m,Supply} + E * u_{m,Labor} = N * u_{m,Product} + N * u_{m,XID} \quad \text{OR} \tag{4a}$$

$$N * u_{m,Product} = L * u_{m,LBI,PSCS} + S * u_{m,Supply} + E * u_{m,Labor} - N * u_{m,XID} \tag{4b}$$

with: $D_{m,Pass\text{-}1} = L * u_{m,LBI,PSCS} + S * u_{m,Supply}$
and with: $D_{m,Total\text{-}Labor} = E * u_{m,Labor}$ and $D_{m,Labor,XID} = N * u_{m,XID}$

Equation (4b) can be rewritten as: $N * u_{m,Product} = D_{m,Pass\text{-}1} + D_{m,Total\text{-}Labor} - D_{m,Labor,XID}$ (5a)

$$u_{m,Product} = (D_{m,Pass\text{-}1} + D_{m,Total\text{-}Labor} - D_{m,Labor,XID}) / N \tag{5b}$$

where $u_{m,Product}$ = normalized value of E-impact variable u_m in product made
where $u_{m,XID}$ = normalized value of E-impact variable u_m in PSCS output qualifying as XID
where $D_{m,Pass\text{-}1}$ = normalized value of E-impact variable u_m in combined supplies and LBI_{PSCS} inputs to PSCS
where $u_{m,Supply}$ = normalized value for E-impact variable u_m in supplies input to PSCS
where $u_{m,LBI,PSCS}$ = normalized value for E-impact variable u_m in LBI_{PSCS} input to PSCS
where S = units of supplies used by PSCS
where L = units of LBI_{PSCS} used by PSCS

Note that $D_{m,Total\text{-}Labor} - D_{m,Labor,XID} \geq 0$, $D_{m,Pass\text{-}1} \geq 0$ and therefore $u_{m,Product} \geq 0$.

5.2.2. Excess Impact Deduction for Allowance Variables (XNRD)

The excess impact deduction for allowance variables is calculated using the formulas as listed in § 5.2.1, however such that the individual labor output for each individual $u_{m,Labor.i}$ is calculated using the *personal sustainable resource use absorption* (PSRA) calculation for allowance variables. All instances where the subscript "XID" is used are replaced by the subscript "XNRD" (*excess natural resource deduction).*

5.2.3. Excess Impact Deduction for Current Damage Variables (XCDD)

The excess impact deduction for current damage variables is calculated using the formulas as listed in § 5.2.1, however such that the individual labor output for each individual $u_{m,Labor.i}$ is calculated using the personal current damage absorption (PCDA) calculation for current damage variables. All instances where the subscript "XID" is used are replaced by the subscript "XCDD" (*excess current damage deduction).*

5.2.4. Excess Impact Deduction for Historic Damage Variables (XHDD)

The excess impact deduction for historic damage variables is calculated using the formulas as listed in § 5.2.1, however such that the individual labor output for each individual $u_{m,Labor.i}$ is calculated using the personal historic damage absorption (PCDA) calculation for current damage variables. All instances where the subscript "XID" is used are replaced by the subscript "XHDD" (*excess historic damage deduction)*.

5.3. Calculation of E-impacts for Products Using an Average

5.3.1. Method B, using Arithmetic Average

Unless other methods are used (and as discussed in § 5.1.2 and shown in figure 3, for an individual E-resource usage larger than the allowance and for any current damage done, an excess impact deduction (XID) needs to be applied to prevent supply chain accumulation. For example, for the following conditions:

- average natural resource use of twice the allowance
- 100% IMACS participation on a global scale
- all required conservation is applied
- no XID correction

, the E-impacts of the products produced would increase by about a factor 1.5 with every consumption cycle. To prevent such supply chain accumulation, about 1/3 of all E-impacts that are inputs to the PSCS would need to be deducted as XID. If no conservation would be applied, about half of all inputs to the PSCS would need to be deducted as XID to prevent supply chain accumulation. Especially early in the global sustainability improvement process, with high natural resource use, high current damage and little conservation capacity available, the EH inputs from labor will on average be about as high as the 1st pass inputs from LBI and supplies. In that case, a simple averaging calculation would reduce the product use and damage impacts to half and would prevent supply chain accumulation. The simplest method to calculate the on average correct E-impacts of products under highly non-sustainable conditions (and to prevent E-impact accumulation) is to calculate the arithmetic average of E-impacts from the labor inputs and from the rest of the inputs (LBI and Supplies) to the product supply chain step (PSCS). In that case the labor input would be used in its absolute form without discrimination between 1st and 2nd pass E-impacts.

$$\overline{u} = \frac{Y + Z}{2} \tag{6}$$

where $\overline{u}$ = calculated average value for E-impact variable u in product ($u_{Product}$)
where Y = value for E-impact variable u in sum of supplies and LBI inputs to PSCS ($u_{Supplies,PSCS} + u_{LBI,PSCS}$)
where Z = value for E-impact variable u in labor input to PSCS ($u_{Labor,PSCS}$)

In order to account for the E-impact balance over the PSCS, the XID would still need to be calculated, however the XID is now the result of the EH balance calculation over the PSCS.

$$u_{XID,Average} = u_{Supplies,PSCS} + u_{LBI,PSCS} + u_{Labor,PSCS} - u_{Product} \tag{7}$$

Under certain conditions it may be advantageous to calculate a weighted average. Producers can make products more sustainable in their use (as many are currently available), but unless consumers actually buy and use them, the manufacturing of such products has no significant positive effect on global E-impacts and sustainability. We may change faster to a sustainable society, when organizations are incentivized to have their employees participate in the IMACS and buy IMACS participating products. Such an incentive could be provided by putting a heavier weight on the E-impacts of their own employees and lesser weight of the E-impacts of their Supplies and LBIs.
The weighted average is calculated as follows:

$$\overline{x} = \frac{\sum_{i=1}^{n} w_i \cdot x_i}{\sum_{i=1}^{n} w_i} = \frac{w_1 x_1 + w_2 x_2 + \ldots + w_n x_n}{w_1 + w_2 + \ldots + w_n} \tag{8}$$

In this formula x_i represents the data values, while w_i represent the weights.
One application of this weighted average would be the data weighted average ($\overline{u}_{m,dw}$) where the data values itself are used as weights. For use under the IMACS, the E-impact variable data can be used as weights. This data weighted average is only needed for two variables (Y and Z), where Y is the E-impact equal to the sum of LBI and supply inputs to the PSCS and where Z is the E-impact of the labor input to the PSCS. The data weighted average is defined as follows:

$$\overline{u}_{m,dw} = \frac{Y^2+Z^2}{Y+Z} \tag{9}$$

The data weighted average has a value between the arithmetic average and the higher of the two data values. In addition, the *exponential weighted average* (EWA or $\overline{u}_{m,ew}$) can be used and is formulated as:

$$\overline{u}_{m,ew} = \frac{Y^{(1+P)}+Z^{(1+P)}}{Y^P+Z^P} \tag{10}$$

The exponential weighted average can be used to allow manipulation of this average towards either the higher of lower of the two values. The EWA has the following properties:

1. For exponent value P = 0, the EWA is equal to the arithmetic average (equation 6).
2. For exponent value P = 1, the EWA is equal to the data weighted average (equation 9).
3. For increasing exponent values P > 1, the EWA moves from the data weighted average towards the higher of the two data values.
4. For reducing exponent values 1 > P > 0 the EWA moves from the data weighted average towards the arithmetic average.
5. For increasingly larger but negative exponent values P < 0, the EWA moves from the arithmetic average towards the lower of the two data values.

Use of an exponential weighted average with exponent values P < 0 would thus favor organizations with employees that have smaller than average E-impacts (above average sustainability). This starts with employee participation and the purchase of participating products. Since the latter are likely to have lower E-impacts, the resulting employee labor has lower E-impacts.
Note that for calculation of the EWA, precautions should be taken to prevent zero values for Y and Z, since $Y^{(1+P)}$ and $Z^{(1+P)}$ are not defined for Y = 0 and Z = 0. The simplest solution: add a very small value (say 0.0001) to each Y and Z. By selecting the value for exponent P, the EWA of two values can thus be moved between the lower and the higher of the two data values. For its use under the IMACS, the data used for the EWA are E-impact values and the name *exponential weighted average* is renamed to *exponential E-Impact Weighted Average* (EIWA). *(8 sheet EDWA)*

5.3.2. Incentive to Improve Sustainability

In paragraph 5.1.2 three reasons were listed for making a correction to the “simple addition” method for calculating the E-impacts of products. The objective to create a strong incentive for sustainability improvements for all participants was set to the highest priority, since reaching the other two objectives would be futile if this would result in little or no incentive to reach sustainable conditions in the first place. For the system described, producers reach lower costs and larger profits by making more sustainable products. Organizations can reduce E-impacts for products made and services provided in two ways:

a) By reducing E-impact in Supplies and LBI that are inputs to the PSCS
b) By reducing E-impact in the Own Employee Labor that are inputs to the PSCS

Under the IMACS, supplies and products needed to make other products, are merely storage vehicles for E-impacts, ultimately consumed by individuals. E-impact values larger than zero in the labor input to the PSCS, reflect the non-sustainable excess of E-impacts consumed by employees. Without employees / consumers striving for improvements b), demanding more sustainable products, organization will have no incentives to make improvements a). This does not work the other way around: there is no expectation that more sustainable products made available, would actually be purchased by consumers without any additional incentive to buy them.

The current situation proves this point; product options that are more sustainable in their use are not purchased by consumers, in preference of non-sustainable alternatives, (e.g. geothermal heat pumps fully powered by roof solar). Method A (calculating the XID) initially provides incentives for improving the IMACS participation rate and to buy PSCS rated products, since higher own employee participation, ($f_{P,i}$) and buying a higher percentage of products as rated products ($f_{m,Rated,i}$), will increase the excess impact deduction (XID) and thus reduce the E-impacts of the products made. This results in the higher product sustainability from which both producers and consumers benefit. Unfortunately, once all employees would participate ($f_{P,i} = 1$) and all buy PSCS rated products ($f_{m,Rated,i} = 1$), any further incentives to reduce the E-impacts of labor are removed, since the EH-impacts of labor are equal to the XID. Any reduction in E-impacts of the labor output results in the same reduction of XID, leaving the E-impacts of products unchanged. Using the XID method A by itself would thus remove the largest incentive to improve product sustainability by not allowing the effect of increasingly sustainable labor to reflect in improved product sustainability values.
A calculation method based on an average would prevent this issue, since for the average of A and B both lowering of only A or only B would reduce the average and thus provide an incentive for improvement.

5.3.3. Combination of Methods (C) to Calculate Product Impacts

Thus far we have two methods to calculate the E-impacts of products and services:

A. Calculate E-impacts of products by adding E-impacts of Supplies and LBI (X) and Labor (Y) and deduct the calculated participation based XID: $U_{m,A,Product} = U_{m,X} + U_{m,Y} - U_{m,XID,Part.}$

B. Calculate E-impacts of products as the (arithmetical or exponential) average of the E-impacts of Supplies + LBI (X) and Labor (Y). $U_{m,B,Product} = \text{Average}\ (U_{m,X} , U_{m,Y})$

Methods A and B have each their own advantages and drawbacks (see table 1). All advantages of methods A and B can be combined without any drawbacks in method C.

C. Calculate the E-impacts of products and services as the (arithmetic, data weighted or exponential) average of methods A and B. $U_{m,C,Product} = f_{Correction} * \text{Average}\ (U_{m,A,Product} , U_{m,B,Product})$

where $U_{m,A,Product}$ = E-impact U_m for product or service calculated using method A
where $U_{m,B,Product}$ = E-impact U_m for product or service calculated using method B
where $U_{m,X}$ = E-impacts U_m of Supplies and LBI (X)
where $U_{m,Y}$ = E-impacts U_m of Labor (Y)
where $U_{m,XID,Part.}$ = Excess impact deduction calculated based on participation for U_m
where $U_{m,C,Product}$ = E-impact U_m for product or service calculated using method C
where $f_{Correction}$ = Correction factor to scale E-impacts of production to consumption

For method B, I want to give equal weight to the inputs for calculation of the average. The arithmetic average assigns equal weights to $U_{m,X}$ and U_{mY} and is therefore the best type of average for method B. For method C, the arithmetic average is best at the initial low rates of participation, since it gives equal weight to methods A and B. However, at 100% participation rates, the arithmetic average for method A would exclude all E-impacts from employee labor ($U_{m,A,Product} = U_{m,X}$) and calculate E-impacts of the global product portfolio at half the correct value. Under 100% participation conditions the exponential average using an exponent value of unity (Q = 1) for method C would return the larger of the two values and would under those conditions reflect the correct outcome. For an exponent value of zero (Q = 0) the exponential average is equivalent to the arithmetical average (see Methods). For method C, a gradually increase for exponent Q, starting at Q = 0 for zero % participation to Q = 1 at 100% participation, would meet the start and end conditions. A linear increase between of Q between 0% and 100% participation is the simplest option.
While method C now produces E-impacts outcomes on a global level that best incorporate the various forces maximizing future sustainability, the values produced are not yet correct. The total of E-impacts of products and services produced ($U_{m,Produced}$) over a long period needs to be equal (on average) to the total amount of products and services consumed ($U_{m,Consumed}$) over the same period. A correction factor $f_{Correction}$ is needed to scale the calculated model average to the correct value calculated for the E-impact balance of the global average product portfolio.

$$U_{m,C,Produced, Reginal} = U_{m,C,Consumed, Regional} = U_{m,C,Calculated,Regional} * f_{Correction,Regional} \quad (11)$$

The values for correction factor $f_{Correction}$ are a function of participation but are independent of the magnitude and type of E-impacts. For the initial zero participation conditions, values for correction factor $f_{Correction}$ are calculated as:

$$f_{Correction} = U_{m,Y} / (U_{m,A,Product} + U_{m,B,Product})/2 \quad (12)$$

To check whether the results of the correction are as desired (whether $U_{m,C,Product} = U_{m,Y}$), the Result ratio R_{Result} is calculated as:

$$R_{Result} = U_{m,C,Product} / U_{m,Y} \quad (13)$$

Later values for correction factor $f_{Correction}$ are calculated as:

$$f_{Correction,Period\ N+1} = f_{Correction,Period\ N} / R_{Result},_{Period\ N} \quad (14)$$

The Excel model reflecting the above is available as *(8).* For a future case where all employees are IMACS participants buying only IMACS participating products and services, all transactions are stored in the EIMCS database. All E-impacts enter the supply chain as LBIs. Since all transactions have time and date records, all LBIs that are recorded as inputs to PSCSs and ISCSs over a year can be identified and added. Globally the sum of E-impacts for all products and services produced is equal to the sum of all LBIs.

$$U_{m,C,Produced} = \sum_{i=0}^{N} U_{m,i,P} = \sum_{i=0}^{N} U_{m,i,LBI,P} \quad (15)$$

where $U_{m,C,Produced}$ = sum of E-impacts U_m of all global products and services produced during period P
where $U_{m,i,P}$ = E-impacts U_m of product or service i of N produced during period P
where P_i = product or service i of N sold as participating products and services
where $U_{m,i,LBI,P}$ = LBIs $U_{m,i}$ all global products and services i of N produced during period P
where $LBI_{m,i,P}$ = LBI U_m for all ESCSs in supply chain used to produce product or services i of N over period P

The period P used for the summation in equation (14) needs to be sufficiently long to include most or all LBIs that were inputs to all upstream supply chain steps representing the Supplies and Employee Labor used in the period. Even if a one-year period is used, some Supplies predate the one-year period and a fraction of the total LBIs for the product are "hidden" as an unknown fraction of theses Supplies predating the one-year period. That is typically the case for agricultural products like cereals and meats. Cereals (wheat, corn, rice) are grown seasonally and stored until the new harvest comes in (typically one year later). However, more is stored in order to provide adequate food security in case of lesser than expected future harvests. This means that the average storage period is more than one year. Equation (15) can be extended to reflect the missing amount of LBI for the remainder of period longer than P.

$$U_{m,C,Product} = (\sum_{i=0}^{N} U_{m,i,P} = \sum_{i=0}^{N} U_{m,i,LBI,P})_{Period,P} + f_{LBI,Supplies,P+\Delta t} * U_{m,i,Supplies,P+\Delta t} \quad (16)$$

where $f_{LBI,Supplies,P+\Delta t}$ = the fraction of E-impacts $U_{m,i,LBI,P+\Delta t}$ that as included in $U_{m,i,Supplies,P+\Delta t}$
where $U_{m,i,Supplies,P+\Delta t}$ = Supplies predating period P

At first implementation, only a tiny fraction of all purchases will represent participating products and services and only small fractions of supply chains are available as "rated" and interconnected supply chain steps. Initial values for the E-impacts of products and services ($U_{m,C,Produced}$) will need to be estimated using Product Lifecycle Assessment and (P-LCA) and environmentally extended input-output lifecycle assessment (EEIO-LCA).

6. References

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6. Recommendation on the use of Environmental Footprint methods, 16 December 2021, Directorate-General for Environment Recommendation on the use of Environmental Footprint methods (europa.eu)
7. See Excel file "XID_Calculations" sheet "EDWA". [Provide reference and/or weblink to file location on server where this file is stored, once this file is saved there.]
8. See Excel file "XID_Calculation" sheet "Transitions". [Provide reference and/or weblink to file location on server where this file is stored, once this file is saved there.]
9. Next revision improvements: It looks like (on 5/26/23 and after Bob's review) the calculation model used to calculate the correction factor $f_{Correction}$ is made for the general case, allowing it's use for both allowance and current damage variables. Check that this calculation indeed applies unchanged to both types of variables. If this is confirmed, state at the most appropriate location in paragraph 3 or 4 that this is the case.
10. Next revision improvements: Update formulas used in Excel calculation sheets XNRD, XCDD and XHDD for the formulas derived in section 5 and verify correctness of calculation results using examples.
    a. (See Excel file "XID_Calculations", sheet XNRD, XCDD and XHDD)
11. Next revision improvements: Describe how $u_{m,XID,Participation}$ is calculated. Mention that normalized values are used for the calculation of the of the E-impacts for products and services and that these values can be converted back to original E-impact variable values.
12. Next revision improvements: Describe how $u_{m,XID,Participation}$ is calculated. Mention that normalized values are used for the calculation of the of the E-impacts for products and services and that these values can be converted back to original E-impact variable values.

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