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Published in:
International Journal of Life Cycle Assessment

DOI (link to publication from Publisher):
10.1007/s11367-017-1398-4

Publication date:
2018

Document Version
Accepted author manuscript, peer reviewed version

Citation for published version (APA):
Weidema, B. P., Schmidt, J. H., Fantke, P., & Pauliuk, S. (2018). On the boundary between economy and environment in life cycle assessment. *International Journal of Life Cycle Assessment*, *23*(9), 1839–1846. https://doi.org/10.1007/s11367-017-1398-4

This is a post-peer-review, pre-copyedit version of an article published in [The International Journal of Life Cycle Assessment]. The final authenticated version is available online at: https://doi.org/10.1007/s11367-017-1398-4

On the boundary between economy and environment in Life Cycle Assessment

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Abstract

Purpose: We investigate how the boundary between product systems and their environment has been delineated in Life Cycle Assessment and question the usefulness and ontological relevance of a strict division between the two.

Methods: We consider flows, activities and impacts as general terms applicable to both product systems and their environment, and propose that the ontologically relevant boundary is between the flows that are modelled as inputs to other activities (economic or environmental) – and the flows that – in a specific study – are regarded as final impacts, in the sense that no further feedback into the product system is considered before these impacts are applied in decision-making. Using this conceptual model, we contrast the traditional mathematical calculation of the life cycle impacts with a new, simpler computational structure where the life cycle impacts are calculated directly as part of the Leontief inverse, treating product flows and environmental flows in parallel, without the need to consider any boundary between economic and environmental activities.

Results and discussion: Our theoretical outline and the numerical example demonstrate that the distinctions and boundaries between product systems and their environment are unnecessary and in some cases obstructive from the perspective of impact assessment, and can therefore be ignored or chosen freely to reflect meaningful distinctions of specific LCA studies. We show that our proposed computational structure is backwards compatible with the current practice of LCA modelling, while allowing inclusion of feedback loops both from the environment to the economy and internally between different impact categories in the impact assessment.

Conclusions: Our proposed computational structure for LCA facilitates consistent, explicit, and transparent modelling of the feedback loops between environment and the economy and between different environmental mechanisms. The explicit and transparent modelling, combining economic and environmental information in a common computational structure facilitates data exchange and re-use between different academic fields.

Key-words: flows, activities, impacts, computational structure, Leontief inverse, ontology

1. Introduction

The boundary between economic activities and their environment, i.e., everything outside the economy[1], in Life Cycle Assessment (LCA) – and the corresponding distinction between the Life Cycle Inventory Analysis (LCI) and Life Cycle Impact Assessment (LCIA) phases - can be seen as a historical reminiscence, since the early development of LCA was mainly focussed on the inventory (LCI) part quantifying chemical emissions and resource inputs, with only a very rudimentary assessment of consequent environmental impacts.

In this article we investigate how the boundary between product systems and their environment has been delineated in LCA until the present. We demonstrate how avoidance of hard-coding of this boundary can facilitate more comprehensive and consistent modelling of the different feedback loops between the environment and economic activities and provide incentives for data re-use between assessments.

The technique of quantifying the resource use and emissions along a product life cycle, which became known as Resource and Environmental Profile Analysis (*REPA*), was developed by the Midwest Research Institute in the early 1970's (Hunt et al. 1992). A study on beverage containers conducted by the Midwest Research Institute for the US Environmental Protection Agency (Hunt et al. 1974) is often referred to as a model study that marks the beginning of the development of LCA. In Europe, equivalent pioneering work was done by Boustead & Hancock resulting in their much-cited Handbook of Industrial Energy Analysis (1979).

Most of the early studies aggregated data within categories (e.g. emissions to air, emissions to water, industrial solid waste) *on the basis of mass*, although the difference in harm caused by different substances within the same category was recognised (Hunt et al. 1992).

In Europe, a catalysing role was played by the Swiss environmental protection authorities BUS (later BUWAL, now BAFU) in financing a study on packaging materials (BUS 1984), which was cited in many early studies, both as a data source and due to the novel impact assessment method applied. This method used health standards to aggregate data on environmental loadings under a limited number of headings, i.e. volume of polluted air and volume of polluted water, the so-called *critical volume* approach (Nagel et al. 1999). Interestingly, CO_2 was not included as an emission in these early studies, as it was not yet seen as an environmentally relevant emission. Another important Swiss contribution to the debate on impact assessment was the concept of *ecological scarcity* first presented by Müller-Wenk (1978) and further developed, e.g. by Ahbe et al. (1990).

It was not until the early 1990'ies that the 'A' in the acronym LCA changed from standing for Analysis to stand for Assessment. By then, damage-oriented impact

[1] For a discussion of this "surrounding" definition of the environment versus more narrow definitions, see the end of this section.

assessment methods were developed in a number of national projects: The product ecology project in Sweden, which developed the EPS method using monetarisation to arrive at single scores per product (Steen & Ryding 1992), and the National Reuse of Waste Research Programme (NOH) methodology project in the Netherlands (Heijungs et al. 1992), and the Environmental Design of Industrial Products (EDIP) project in Denmark (Wenzel et al. 1997), which both categorised impacts according to environmental themes.

Since then, there has been much development in ecological modelling and impact assessment, and this has led to questioning the relevance of the strict division between LCI and LCIA (Heijungs et al. 2009), an issue that we wish to further formalise with this article.

Pauliuk et al. (2016) propose a practical ontology for socio-economic metabolism, in which they recommend to avoid 'hard-coding' of system boundary classifications, so that modellers from different disciplines can share and re-use data while applying their own classifications of objects and events and system boundaries, to produce tailor-made system descriptions and indicators that fit the research questions at hand. This recommendation of avoidance of hard-coding also concerns the boundary between economic activities and their environment, for example in LCA.

Before we go on, we need to clarify that in this article we generally refer to the term "environment" in the way it is defined in ISO 14001: "surroundings in which an organization operates, including air, water, land, natural resources, flora, fauna, humans, and their interrelation." The environment is thus defined as complement, i.e., everything not included in the analysed economic activities, including not only ecosystems and natural resources but also humans and socio-cultural resources as endpoints or "Areas of Protection". This may appear confusing in the context of traditional LCA, since a more narrow use of the term environment is common in the community of LCA practitioners. This more narrow usage, limited to specific biophysical mechanisms and flows, may be accentuated by the lack of an explicit definition of the environment in the ISO 14040-series, which provides the further specifications of ISO 14001 when applied to product systems. This difference in usage of the term environment is a further illustration of the point made above: That by avoiding hard-coding any specific narrow usage of the term environment, modellers from different disciplines may share and re-use data while applying their own definitions. In line with this, it is possible to apply the proposals and conclusions put forward in this article, even when using a more narrow definition of "environment".

2. The distinction between LCI and LCIA in the ISO 14040-series

In the technique of LCA, as codified in the ISO 14040-series, a distinction is made between Life Cycle Inventory analysis (LCI) and Life Cycle Impact Assessment (LCIA).

An LCI is a description of the flows in and out of the economic activities that represent a product system, i.e. the subsystem of human activities and their product flows that represents the different stages in the production, use and final disposal of a product, followed up to the point where the flows are classified as elementary flows. An elementary flow is defined as a "material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation" (ISO 14040). An example of an elementary flow is CO_2-emissions to ambient air expressed in mass units.

The LCIA then further describes the pathways or mechanisms in the environment that these elementary flows contribute to, to the level that is necessary to understand and evaluate the magnitude and significance of the potential impacts of the product system on its environment. The modelling of the environmental mechanisms may end at environmental midpoints (by mapping different elementary flows to environmental mechanisms and converting them to a common unit of measurement, such as Global Warming Potential expressed in kg CO_2-equivalents, or Acidification Potential expressed in kg SO_2-equivalents) or may be carried forward to environmental endpoints (by converting the midpoint impact indicators to increasingly decision-relevant endpoints, such as Human health measured in Disability-Adjusted Life-Years or Ecosystem quality measured in Biodiversity-Adjusted Hectare-Years). Endpoint indicators may even be monetarised, although the latter may be seen as dissuaded by the ISO standards. In LCIA practice, the modelling of environmental mechanisms is typically summarised in terms of characterisation factors (representing either midpoint or endpoint impacts per elementary flow) that are then simply multiplied on the amount of elementary flows.

3. The unsharp boundary between LCI and LCIA

However, the distinction between LCI and LCIA (and between product systems and their environments) is not sharply defined (Heijungs et al. 2009), as can be seen for example by the pragmatic inclusion of human-controlled landfills in the LCIA (see Annex A in Weidema et al. 2013), and the on-going discussion on whether to regard pesticide applications to an agricultural field or pesticide emissions from a field as the elementary flows (Rosenbaum et al. 2015).

Activities in the economy are characterised by having product outputs, i.e. goods or services with a market or non-market value, including household production and consumption and waste treatment services. In the common notion, the direct service of economic activities to other economic activities distinguishes these from processes in the environment. But with the increasing human colonization of the Earth's ecosystems (Fischer-Kowalski 1999) and the increasing attention to "ecosystem services" (Koellner et al. 2013, Arbault et al. 2014), the relevance of this distinction seems to fade away: Some environmental mechanisms can be regarded as having a measurable economic value, and product systems need both economic and environmental processes to operate.

Furthermore, the current use of characterisation factors in LCIA implies a unidirectional understanding of the environmental impact pathways, since it does not allow for explicit inclusion of feedback loops between the environment and the economy within the LCA models, e.g. when impacts on human health cause an increase in the demand for hospital services (Sheffield et al. 2011), or when crop production is affected positively or negatively by atmospheric pollution (Lawlor 2005). The unidirectional understanding of the environmental impact pathways also means that it is not possible within the LCA model to explicitly represent feedback loops within the environment, e.g. when global warming leads to the melting of permafrost leading to additional CO_2 and CH_4 emissions (O'Connor et al. 2010). We acknowledge that in some current impact assessment methods, such feedbacks between environmental compartments are taken into account in the characterisation factors, but re-use and modification is made unnecessarily difficult when these feedbacks are not explicitly represented in the model.

We can conclude that there is no consensus on the principles on where to draw the boundaries between LCI and LCIA; between the considered product system and its affected environment; and between product flows and elementary flows. For the reasons given in the previous paragraph, such distinctions and boundaries can reduce transparency and completeness of impact pathway modelling. While such distinctions and boundaries can be meaningful in specific contexts, they appear to have no *general* meaning and ontological relevance, cf. Pauliuk et al. (2016).

4. A generalised concept of flows, activities and impacts

Instead, we propose that the ontologically relevant boundary in LCA is between the flows that are further modelled as input or output *flows* to and from *activities* (in both the economy and the environment) – and the *impacts* that – in a specific study – are regarded as final, in the sense that these impacts are applied in decision-making without further consideration of feedbacks into the (economic and environmental) system.

We illustrate our point in Figure 1, using the activity-object matrix notation common to Leontief and Ghosh input-output models, which has a long tradition both in the study of economics and ecosystems (Suh 2005) [2]. The idea of representing the economy and the environment in a single 4-quadrant matrix as in Figure 1 was proposed already by Daly (1968) and Isard (1969), and elaborated by Heijungs (2001) in the context of LCA. Except for some minor deviations in terminology, our work does not intend to deviate from that of Daly, Isard and Heijungs, but rather to provide a further elaboration on the implications for its application to LCA practice.

[Insert Figure 1 around here]

For figure 1 we define:

- *Activity* as "making or doing something", including both human activities (production, consumption, and market activities, as well as accumulation

[2] As described by Suh (2005), this notation treats all activities as having linear production functions (having only linear relationships between input and output flows), which is a simplification that requires a prior disaggregation of activities with non-linear functions into stepwise linear functions.

of stocks) and environmental mechanisms (e.g. radiative forcing, deposition, pollination), irrespective of their economic significance.

- *Flow* as a “causal, directional exchange between two activities”. The direction of the flows is usually indicated by a sign convention, e.g. negative for inputs and positive for outputs, while the direction of the causality is independent of the sign.
- *Object* as an “entity that is able to be exchanged between two activities, produced or consumed by activities, or stored within an activity (stock)”.
- *Impact* as a “causal, directional relationship between an activity and an environmental issue of concern”.

The first two definitions are everyday language versions of the set-theory-based definitions of ‘process’ and ‘flow’, respectively, suggested by Pauliuk et al. (2016).

Figure 1 includes all flows relevant to both LCI and LCIA. The elements of the illustrated matrices thereby represent:

- **A**: Product flows between activities within the economy;
- **B**: Elementary flows initiated in the economy influencing its environment, e.g. resource abstractions or chemical emissions;
- **C**: Flows between activities in the environment, traditionally summarized in LCIA as characterisation factors, which can be subdivided into fate, exposure, and effects factors; we maintain here the terminology for legacy reasons, while the matrix could also have been simply characterised as “flows in environment” in parallel to matrix **A**;
- **D**: Feedback flows initiated in the environment influencing economic activities. These mechanisms are not included in traditional LCA calculations;
- **E**: Impacts that are not further modelled as flows. Depending on the extent of the flow modelling, impacts may arise both from activities in the economy and from activities in the environment.

The traditional distinction in LCA is between product flows within the economy and elementary flows on the boundary to the environment. In reference to Heijungs and Suh (2002), the mathematical calculation of the life cycle impacts is performed by first inverting the economic activity matrix **A** of dimension nXn, which by multiplication with the final demand vector (or any other exogenous driving vector) **f** of dimension nX1, produces the vector of scaling factors (**s**), which are then applied to the matrix of elementary flows $\mathbf{B_T}$ (where T refers to the traditional part of **B**, limited to the rows for the direct elementary flows from the economic activities), thus providing the vector of life cycle totals of each elementary flow per unit of output of each activity (**m**):

$$\mathbf{s} = \mathbf{A}^{-1}\mathbf{f}$$

$$\mathbf{m} = \mathbf{B_T s} = \mathbf{B_T A}^{-1}\mathbf{f}$$

Finally, these life cycle inventory totals represented by the elements of **m** are multiplied by the characterisation factors in $\mathbf{C_T}$, where T refers to the elements of **C** containing the characterisation factors, i.e. not including the -1's (the -1's simply tell us that the characterisation factors are provided per unit of input to the environmental mechanisms) to arrive at the final vector of life cycle impacts (**g**):

$$\mathbf{g} = \mathbf{C_T m} = \mathbf{C_T B_T A^{-1} f}$$

This traditional calculation neither allows modellers to include feedbacks from the environmental activities or mechanisms (LCIA) to the economic activities modelled in the LCI, nor does it enable them to consider couplings between different impact categories in the LCIA.

To overcome these two central limitations of current LCA practice we propose to calculate the life cycle impacts directly by inverting the combination of matrices **A** to **D** shown in Figure 1, i.e. the entire matrix **X** = [[**A**,**D**];[**B**,**C**]] and multiplying the resulting scaling factors in vector **s** on the impact factors in matrix **E**:

$$\mathbf{g} = \mathbf{Es} = \mathbf{EX^{-1}f}$$

thus treating product flows and other flows (in matrices **B**, **C** and **D**) in parallel, without the need to consider any boundary between economic activities (LCI activities) and other activities (environmental LCIA activities or mechanisms).

The addition of the **E** matrix isolates the normative decision of "what is an issue of concern", and especially at what point along the impact pathway the "impact" is defined, from the flows in the economy and environment that can be subject of empirical investigation. Thus, the elements of the **E** matrix represent those intermediate flows (or combination of flows) within the economy-environment continuum that in a specific assessment context are linked to the defined "impacts".

5. Numerical example

We illustrate our proposal with the following numerical example of the emissions of NO_x and CO associated with 1 km of car driving. The example is not intended to be exhaustive, and has on purpose been limited to two emissions and two impact pathways that are well-known to LCA practitioners and which have feedback mechanisms to the economy that are relatively simple to understand. The feedback from the two impact pathways that we have included in the example, namely on agricultural output and on health care expenditures, are both among the more important feedback mechanisms for many impact categories, although the two impact categories in the example are not among the most important for these feedbacks. We can mention much more important, but more complicated, impact categories with a large amount of feedback mechanisms, such as global warming, and there are also many feedback mechanisms currently not included in mainstream LCA, such as the influence of sedimentation on the output from hydropower dams, the influence of toxic substance emissions on pollination and thus on agricultural output, or the importance of changes in soil organic matter for the fertiliser requirements. When including new midpoints or feedback mechanisms, it is of course important to avoid double-counting of impacts. Inclusion of such feedback mechanisms may be most relevant for large-scale functional units and transition studies, for example, when applying LCA thinking to the transition of the energy system as in Hertwich (2015) or Daly et al. (2015) or to sustainable consumption, as in de Konig et al. (2016). It is not the purpose of this article to provide data for all of these impact pathways, nor to evaluate which of these would be most important to include in different LCA studies.

In our example, we consider only three products, namely the service of car driving, products of agriculture, and the service of health care. The **A** matrix is an identity matrix, and the final consumption vector for 1 vehicle-km is:

$$\mathbf{f_T} = \begin{pmatrix} \mathbf{1} \\ \mathbf{0} \\ \mathbf{0} \end{pmatrix}$$

In Figure 2, the first and second row of the **B** matrix ($\mathbf{B_T}$) contain the NO_x and CO emission factors, respectively, per vehicle-km and the last three rows of the **C** matrix ($\mathbf{C_T}$) contain the characterisation factors for three affected impact categories. Thus, $\mathbf{C_T}$ does not include the part of C (with -1's) that tells us the amount of (input) flow the characterisation factors are provided for. Note that we used the inverse of the usual characterisation factors given per unit of the impact category endpoint, since we here express them per unit of input flow to the environmental mechanism, i.e. per unit of emission from the economic activities.

[Insert Figure 2 around here]

The traditional calculation:

$$\mathbf{g} = \mathbf{C_T m} = \mathbf{C_T B_T A^{-1} f_T}$$

provides the result for the three considered impact categories:

$$\mathbf{g} = \begin{pmatrix} 0.00104 \\ 8.34 \\ 0.0462 \end{pmatrix}$$

[Insert Figure 3 around here]

In the expanded matrix (Figure 3), "Ozone dispersal" and "Nitrogen deposition" have been added as new midpoints. "Ozone dispersal" is a new common midpoint towards "Human exposure to ozone" and "Vegetation exposure to ozone". "Nitrogen deposition" is a new common midpoint towards "Eutrophication", where the 62% of the N ends up, and the fate of the remaining 38%, which ends up on agricultural soils where they have a fertiliser effect that loops back into the economy (along with the ozone impact on crops and the health care effects from respiratory organics). There is now no longer any direct impact from the NO_x and CO emissions on "Human exposure to ozone", "Vegetation exposure to ozone", and "Eutrophication" because these impacts are now indirect via the new midpoints. In spite of the new midpoints, the original midpoint impacts have been kept the same in both the traditional and the expanded matrix, since we do not wish to imply any difference in endpoint modelling.

In **B** of the expanded matrix (Figure 3), it should be noted that only the first two rows contain non-zero values, i.e. the part corresponding to $\mathbf{B_T}$ in Figure 2. Further, matrices **A** and **C** are square. All columns in **C** have -1's on the main diagonal, specifying that the characterization factors are given per unit of input flow to the environmental mechanism. Correspondingly, values added in matrix D are negative when the emission leads to an increased requirement (input) of health care services or a reduced yield (output) of agricultural products, while the positive value for nitrogen deposition reflects the fertiliser effect (increase in output). To match the dimensions of the full 10 by 10 matrix **X**, the final consumption vector **f** must of course also be expanded to a 10 by 1 vector.

When we invert the full **X** matrix:

$$\mathbf{g} = \mathbf{Es} = \mathbf{EX}^{-1}\mathbf{f} = \mathbf{E}\,[[\mathbf{A},\mathbf{B}];[\mathbf{C},\mathbf{D}]]^{-1}\mathbf{f}$$

the result for the three considered impact categories becomes:

$$\mathbf{g} = \begin{pmatrix} 0.00105 \\ 8.37 \\ 0.0466 \end{pmatrix}$$

Note that without the feedbacks in matrix **D**, the result would have been exactly the same as for the traditional calculation.

6. Implications for the current practice of LCA

In summary, the expanded matrix of inter-activity flows:

- allows for explicit and transparent modelling of feedback loops between and within the environment and the economy (**D**);
- allows for more detailed modelling of the environmental mechanisms (**C**), especially where the same mechanism contributes to several impacts (as exemplified here by ozone creation and nitrogen deposition), something that would be modelled in parallel in the traditional LCA approach and folded up into the characterisation factors;
- allows for explicit and transparent modelling of additional feedback loops within the **C** matrix itself, e.g. when global warming leads to additional emissions of CO_2 and CH_4 due to smelting of permafrost (not included in the example);
- is 'backwards compatible' with the current practice of LCI and LCIA modelling, cf. the example;
- allows for flexibility for data providers and users as to whether an activity

is defined as being part of the economy or part of its environment (and does not require this distinction to be applied at all), ensuring that results are not affected by this choice, e.g. for landfills and pesticide applications;

- provides a formal basis for increased data sharing and re-use[3] between practitioners from individual disciplines across the economy-environment divide, due to the explicit and transparent impact modelling;
- retains a linear description of the system, with the advantages and disadvantages described by Suh (2005).

The full advantage of the new modelling options will of course only be realised when comprehensive data are entered into the matrix. However, our proposed direct calculation of the life cycle impacts from the expanded matrix does not in itself require more data and it represents a computational simplification relative to the traditional two-step calculation of LCI results and subsequent LCIA calculations.

7. Conclusion

Our theoretical outline and the example above demonstrate that the distinctions and boundaries between matrices **A**, **B**, **C** and **D** are unnecessary from the perspective of impact calculation, and can therefore be ignored or chosen freely to reflect meaningful distinctions of specific LCA study contexts.

Furthermore, the inclusion of matrices **B**, **C**, and **D** in the matrix inversion allows for the inclusion of explicit feedback loops both between different environmental mechanisms and between the environment and the economy.

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[3] We see the beauty of the expanded matrix in the inclusion of activities for which it is not always clear whether they are part of the economy or not (landfills, plants on fields, agricultural soils, forests, etc.). Hence this matrix represents a comprehensive database for integrating knowledge from specific disciplines dealing with landfills, plants, etc., irrespective of whether these disciplines consider themselves as relevant for economic accounting, ecological modelling or LCA.

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Figure legends

Figure 1. Matrix showing the ontologically relevant concepts of activities, flows and impacts and the fuzzy boundaries between the human economy and its environment.

*Figure 2. The traditional matrix for the numerical example. Colour coding as in Figure 1 shows the delimitation of matrices **A**, **B**, **C** and **D**. Subscript T is introduced to point out that only parts of matrix **B** and **C** enter into the traditional calculation.* $\boldsymbol{B_T}$ *refers to the traditional part of **B**, limited to the rows for the direct elementary flows from the economic activities.* $\boldsymbol{C_T}$ *correspondingly refers to the elements of **C** containing the characterisation factors, i.e. not including the part of **C** (with -1's) that tells us the amount of (input) flow the characterisation factors are provided for. In accordance with normal LCA practice, flows have been normalised to the unit flow of the activity, and the units of the columns refer to the functional input or output (the flow on the diagonal) of each activity, in order to express the flows as proportions between specific inputs and outputs (e.g. NOx emissions in kg/vehicle-km and eutrophication in m2 UES/kg NOx). Characterisation factors from Hauschild & Potting (2005).*

Figure 3. The expanded matrix for the numerical example. The data added are rough estimates for illustrative purposes only.

Figure 1:

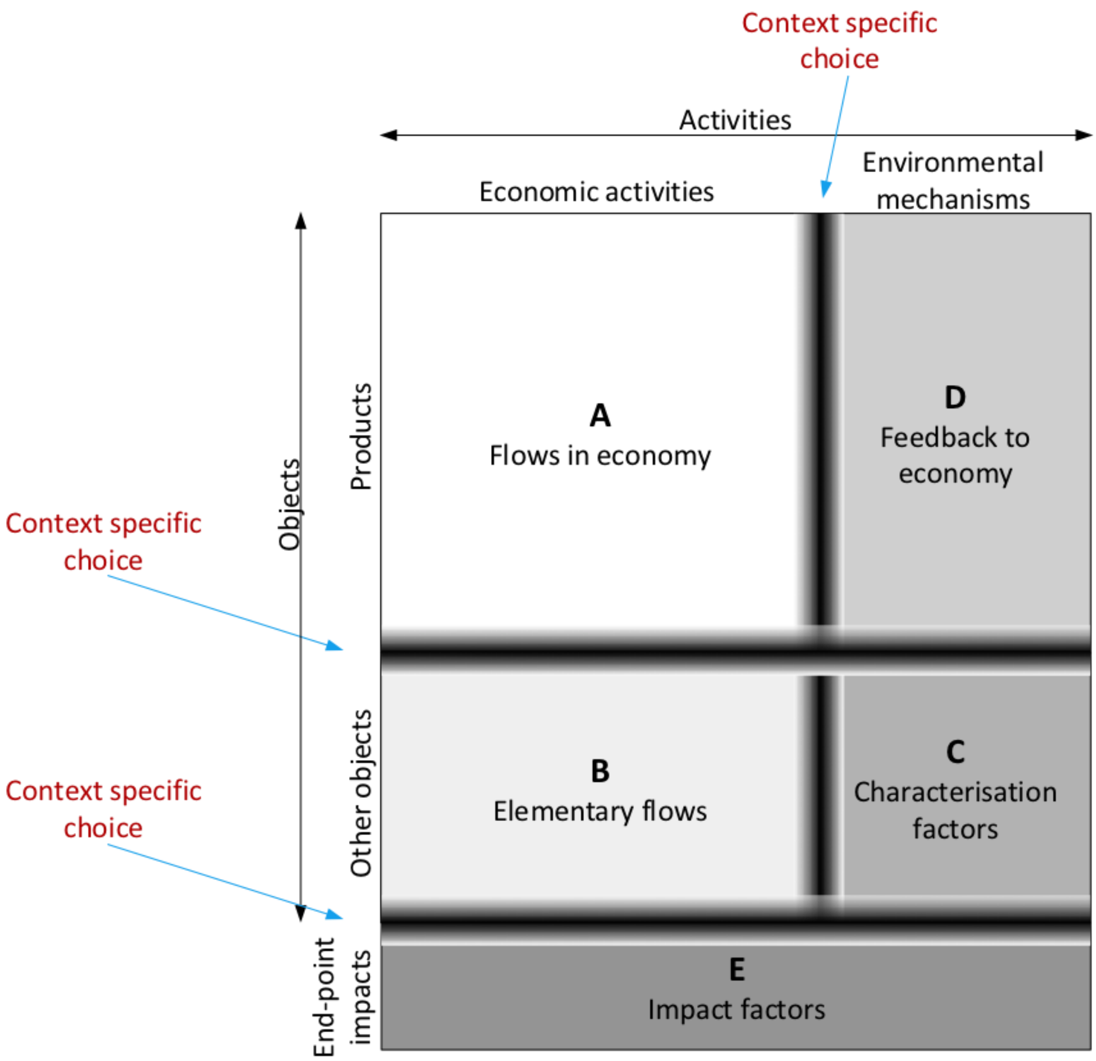
Context specific choice
Activities
Economic activities
Environmental mechanisms
Objects
Products
A
Flows in economy
D
Feedback to economy
Context specific choice
Other objects
B
Elementary flows
C
Characterisation factors
Context specific choice
End-point impacts
E
Impact factors

Figure 2:

Traditional calculation:		Car driving	Agriculture	Health care	NO_x-trans-formation	CO-trans-formation
		vehicle-km	EUR	EUR	kg	kg
Services of car driving	vehicle-km	1				
Product of agriculture	EUR		**A** 1			
Services of health care	EUR			1		
NO_x-emission	kg	0.0014	0.005	0.00006	-1	
CO-emission	kg	0.01	$\mathbf{B_T}$			-1
Human exposure to ozone	pers*ppm*h				0.2	0.076
Vegetation exposure to ozone	m2*ppm*h				1600	$\mathbf{C_T}$ 610
Eutrophication	m^2 UES				33	

Figure 3:

Expanded calculation:

		Car driving vehicle-km	Agriculture EUR	Health care EUR	NO_x-trans-formation kg	CO-trans-formation kg	Ozone dispersal m^2*ppm*h	Effect of ozone on humans pers*ppm*h	Effect of ozone on vegetation m^2*ppm*h	Nitrogen deposition kg N	Effect of eutrophication m^2 UES
Services of car driving	vehicle-km	1									
Product of agriculture	EUR	**A**	1					**D**	-0.0003	0.456	
Services of health care	EUR			1				-0.01			
NO_x-emission	kg	0.0014	0.005	0.00006	-1						
CO-emission	kg	0.01	0.01	0.04		-1					
Ozone exposure potential	m^2*ppm*h				1600	610	-1	**C**			
Human exposure to ozone	pers*ppm*h	**B**					0.000125	-1			
Vegetation exposure to ozone	m^2*ppm*h						1		-1		
Nitrate, measured as N	kg N				0.375					-1	
Eutrophication	m^2 UES									88.04	-1
Effect of ozone on humans	pers*ppm*h							1			
Effect of ozone on vegetation	m^2*ppm*h					**E**			1		
Effect of eutrophication	m^2 UES										1