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Natalia Finogenova, Vanessa Bach, Markus Berger, Matthias Finkbeiner

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Hybrid approach for the evaluation of organizational indirect impacts (AVOID): combining product related, process based and monetary based methods

Natalia Finogenova[1*], Vanessa Bach[1], Markus Berger[1] and Matthias Finkbeiner[1]

[1] Technische Universität Berlin, Chair of Sustainable Engineering, Straße des 17. Juni 135, 10623 Berlin, Germany

*Corresponding author: natalia.finogenova@tu-berlin.de, Tel: +493031428455, Fax: +493031421720

ABSTRACT

Purpose: Environmental burden caused by an organization occur both within its boundaries and in its value chain. Organizational Life Cycle Assessment (LCA) was proposed as a method for calculating impacts of an organization throughout its life cycle, nevertheless companies are still lacking a universal approach to conduct inventory analysis and face challenges in data collection. This paper introduces a hybrid approach for compiling the inventory for the indirect activities on organizational level in an effective manner.

Methods: Three existing accounting methods (namely product related, process based and monetary based) are connected within the hybrid approach. The potential to apply each method for an indirect activity is analysed with regard to the system boundary requirements and availability of activity data and emission factors. The calculation procedures are introduced for selected activities. The advantages and limitations of the hybridization on organizational level are discussed. The developed approach is applied in a case study to the automotive supplier Brose Fahrzeugteile GmbH & Co.KG.

Results and discussion: The framework for application of the hybrid approach including the required activity data and emission factors for every indirect activity and each accounting method is provided. The product related and process based methods are recommended as more robust, nevertheless hybridization with the monetary based method might be essential for compiling a comprehensive inventory by limited data availability. Such limitations as double counting, truncation error and insufficient data resolution may influence the results and should be considered when applying the hybrid approach. The case study demonstrated that the proposed approach allowed establishing an inventory for all relevant indirect activities. However, due to missing emission factors only the impact category climate change was calculated for all activities, acidification and water use were quantified for six activities.

Conclusions: The introduced hybrid approach enables selecting the most suitable accounting method for the indirect activities depending on data availability. This promotes application of the Organizational Life Cycle Assessment in particular for small and medium enterprises and companies that do not have access to the commercial LCA datasets. Availability of the emission factors for all impact categories in public databases is essential to provide robust results using the hybrid approach.

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KEYWORDS: organizational indirect impacts, organizational LCA, hybrid approach, supply chain

1. INTRODUCTION

Environmental impacts of an organization occur both within its boundaries (direct impacts) and throughout its value chain (indirect impacts). The latter include, for example, extraction of purchased raw materials and use of sold products. The organization, though not controlling external activities, can influence them indirectly, for example by raw material purchasing (e. g. using recycled materials) or product design (e. g. leading to less energy consumption during the use phase). An overview of indirect activities on organizational level is presented in Fig1. Recent studies evaluating indirect impacts on the organizational level have shown that more than 90% of companies' emissions can be associated with indirect activities (Plambeck, 2012; CDP and Systain, 2014; UNEP, 2015; UN Environment, 2017). Current trends in manufacturing, like outsourcing of production processes and increasing complexity of supply chains, further shift environmental burden from companies to their suppliers (Seuring *et al.*, 2008; Hauchbach, 2013). For this reason, a comprehensive and transparent evaluation of the environmental impacts of an organization can only be performed by considering the company's entire value chain (Martínez-Blanco, Inaba and Finkbeiner, 2015).

Life cycle assessment (LCA) has been broadly applied for the evaluation of the environmental performance of products since decades. On the organizational level, the life cycle approach is often applied to calculate Greenhouse Gas (GHG) emissions associated with electricity consumption, while evaluating other impacts is limited to direct processes (e.g. emissions from production facilities) (Martínez-Blanco *et al.*, 2015). However, a trend towards evaluation of the indirect impacts for organizations can be observed since indirect impacts have recently been included into environmental and sustainability reporting initiatives e.g. Global Reporting Initiative (GRI) (GRI, 2013) and Carbon Disclosure Project (CDP) (CDP, 2015).

During the last years different guidelines for a standardized quantification of the environmental impacts along the value chain of organizations were developed (Martínez-Blanco *et al.*, 2015). These include standards provided by Greenhouse Gas Protocol Initiative (WRI and WBCSD, 2004, 2011), norms issued by International Organization for Standardization (ISO, 2012, 2014), Organizational Environmental Footprint (OEF) (European Commission, 2012) and the Guidance on Organizational Life Cycle Assessment (UNEP, 2015). The focus was initially set on GHG emissions (e.g. GHG Protocol Corporate Value Chain Standard, ISO 14064) due to emerging attention to climate change mitigation policies. The recently published ISO 14072 (ISO, 2014) and Guidance on Organizational LCA (UNEP, 2015) adapt the methodology of product LCA to the organizational level (Finkbeiner and König, 2013; Martínez-Blanco *et al.*, 2015; Martínez-Blanco, Inaba and Finkbeiner, 2015), thus considering a broad range of environmental aspects (multi-impact approach)(Martínez-Blanco <i>et al.</i>, 2015). Applying the multi-impact approach enhances a comprehensive evaluation and prevents burden shifting, i.e. whether avoided emissions lead to an increase of other environmental impacts (Berger *et al.*, 2015).

Although guidelines providing methodologies for data collection and calculation are available (e.g. Technical Guidance for Calculating Scope 3 Emissions (WRI and WBCSD, 2013), quantification of indirect impacts on the organizational level is currently performed by few companies. According to the study of CDP and Systain (2014) only 4% of organizations can calculate all their indirect GHG emissions. A study of CDP; WRI and WWF (2015) analysing indirect GHG emissions of 500 companies of different industrial sectors showed that the highest emissions occur in the production of purchased materials, processing[1] and, use phase of sold products. However, impacts of these activities are quantified by only 30%, 20% and 5% of responding companies, respectively. The main reasons for not quantifying indirect impacts indicated by companies are incomplete data, poor data quality and lacking quantification methods (BSD/Quantis, 2015).

Different calculation procedures exist for calculating indirect activities on organizational level. Nevertheless, most companies are facing difficulties while compiling inventory data. The following main challenges can be identified based on existing literature (Milà I Canals *et al.*, 2011; BSD/Quantis, 2015):

- Data collection is very work-intensive due to a large number of activities
- For some activities, e.g. consulting services or maintenance, emission factors are often not available, especially in public databases
- A wide-ranging product portfolio complicates quantification of the impacts in the use phase of sold products.

These limitations relate in particular to small and medium enterprises (SMEs). As demonstrated by the recent studies (Heidrich and Tiwary, 2013; Witczak *et al.*, 2014), SMEs often are not able to compile large inventories and/or conduct a comprehensive impact assessment, mainly because of lack of expertise, time and cost issues. In order to address some of these challenges this paper introduces a hybrid approach, which enables data collection and quantification of all relevant indirect impacts on the organizational level by connecting different accounting methods. For this purpose, existing calculation approaches are divided into product related, process based and monetary based accounting methods. In section 2 the application of each method including data requirements and calculation procedure is described and recommendations on using each method are provided. The hybrid approach is presented in section 3. The feasibility of the approach is evaluated in the case study of the company “Brose Fahrzeugteile GmbH & Co.KG” (section 4). The strengths and limitations of the approach are discussed in section 5.

2 Application of the existing approaches

In this section the methods to compile inventory data and to quantify impacts on organizational level are described. Recommendations for using a method including activity data, emission factors and potential limitations in data availability for every indirect activity are formulated.

To calculate environmental impacts on organizational level activity data and corresponding emission factors are needed. Activity data represents inventory data linked to an environmental impact, e.g. for the indirect activity *procurement* the amount of all purchased materials differentiated by type (e.g. steel, plastics, intermediate materials). Emission factors convert activity data into potential impacts and are specific for every material or process (e.g. amount of CO_2-equivalents (CO_2e) per one unit of purchased steel).

Data collection on the organizational level can be carried out bottom-up or top-down (ISO, 2014; UNEP, 2015; Lutter *et al.*, 2016). According to the bottom-up approach, impacts are calculated by summing up the impacts of all products manufactured by the reporting company and adding the impacts of the supporting activities not

[1] Processing refers here to the activity *processing of sold products* (not the internal processing within the company), which occurs by the company’s customers and is relevant only for organizations producing intermediate goods

directly related to production (e.g. business trips). The production related impacts are quantified by multiplying the category indicator results of the product LCA studies with the quantity of the manufactured or sold products (depending on the calculated activity[2]) during the reference period (Milà I Canals *et al.*, 2011). It should be noted that while product LCAs are mostly established for the whole product's lifetime, O-LCA studies usually relate to the period of one year and consider the product's lifetime only when calculating the activity *use of sold products*. This issue may cause a discrepancy in the reference period between the organizational and product LCA, which is discussed in the section 5.2 of this paper. In this case, the number of products represents the activity data and the LCA category indicator results the emission factors (Fig2). In this paper this calculation procedure is referred to as *product related accounting*. The top-down approach considers the reporting organization as a whole and accounts for its total upstream and downstream flows. The top-down approach applies the company-wide data and can be divided into *process based* and *monetary based accounting* depending on whether physical process flows (e.g. kg of purchased steel) or monetary units (e.g. $ spent on purchased steel) are used as activity data. Accordingly, process based (e.g. kg CO_2e/1 kg steel) or monetary based (e.g. kg CO_2e/1$ spent on steel) emission factors have to be applied (see Fig2). In the following the application of the product related, process based and monetary based accounting is presented (section 2.1 – 2.3). These three methods are the basis for the hybrid approach (section 3).

Depending on the indirect activity different system boundaries for the emission factors have to be applied (WRI and WBCSD, 2011; UNEP, 2015). The cradle-to-gate factors represent the total life cycle impacts of the foreground processes (e.g. kg CO_2e per production of one ton steel in the activity *procurement*) and have to be used for the activities associated with purchased materials and energy. These processes include the impacts of the upstream supply chain, but do not include the impacts of the company's direct (gate-to-gate) manufacturing processes. For the use of sold products, the impacts throughout the whole use phase have to be considered (WRI and WBCSD, 2011). For all other activities the direct emission factors of the 1st tier suppliers (e.g. emissions from the waste treatment in the activity *waste generated*) have to be applied. The overview of the system boundary requirements for the emission factors is provided in table 1.

2.1 Product related accounting method

Product related accounting can be applied if the life cycle stages considered in the product LCA studies overlap with the activities to be included in the organizational assessment. This applies for *procurement*, *downstream transportation*, *processing*, *use* and *end of life (EoL) of sold products*. Impacts linked to these activities can be quantified using the category indicator results of the product LCA studies.

In other cases attributing a life cycle stage (product LCA) to a specific activity (organizational LCA) is more challenging. The activity *upstream transportation*, for example, includes not only transportation of raw materials needed for the product manufacturing, but also of capital equipment and supporting materials (e.g. cleaning agents). Some of these processes may be partly disregarded in product LCA studies due to the cut-offs in the system boundary. The activities *waste generated* and *purchased energy* refer not only to the product related impacts as well, but include other processes (e.g. energy consumed or waste produced in canteen and office

[2] For upstream activities number of produced products, for downstream activities number of sold products (because not all of the produced products might be sold)

buildings). Therefore, these activities cannot be quantified by only using the product related accounting, but might need additional activity data, e.g. the energy consumption and waste generation of the office buildings. The rest of the indirect activities (e.g. *business trips*, *employee commuting*) are usually completely excluded from the system boundaries of product LCA studies (UNEP, 2015). For this reason, the product related accounting cannot cover them. Recommendations for the application of the product related accounting are summarized in Fig3. The calculation procedure using the product related accounting is introduced for the indirect activities *procurement* and *use phase of sold products*.

Procurement

The calculation of the activity *procurement* is performed by multiplying the number $Q^{produced}$ of products *p* produced during the reference period with the category indicator results[3] *CI* of these products for the cradle-to-gate (CtG) phase. As stated above, the cradle-to-gate category indicator results refer to the foreground processes and do not include the manufacturing stage within the organization. The results are summed up over the whole product portfolio (see eq. 1).

$$Procurement = \sum_P Q_p^{produced} * CI_p^{CtG} \qquad \text{(Equation 1)}$$

Use of sold products

The category indicator results of the use phase are applied to quantify impacts in the activity *use phase of sold products*. Different scenarios for the use phase can exist depending e.g. on consumer behaviour or, for intermediate products, final product use. For this reason the use phase category indicator results can vary for the same product. To provide a joint result on the company level the share of products entering each use phase scenario should be determined. This can be performed using product specifications, surveys regarding consumer behaviour and, for intermediate products, data regarding the final product's use. On this base, multiple use phase scenarios $j_{1,\dots,n}$ can be assumed for the respective shares $\boldsymbol{\omega}_j$ of the product portfolio ($\sum_j \omega_j = 1$). The calculation is performed by multiplying the amount Q^{sold} of products *p* sold during the reference period with the category indicator results *CI* of each use phase scenario and the corresponding share $\boldsymbol{\omega}_j$ of the products entering the use phase scenario j (see eq. 2). The results are then summed up over the whole product portfolio.

$$Use\ of\ sold\ products = \sum_{P,j} Q_p^{sold} * CI_{p,j}^{use} * \omega_j^{use} \qquad \text{(Equation 2)}$$

The activity data for the product related accounting can be collected internally, since information regarding numbers of produced and sold products is usually stored within the company's' internal reporting systems. The emission factors represent the category indicator results and are available after the LCA studies of products were conducted. In other case, before applying the product related accounting, product LCA studies need to be carried out. This usually requires access to the commercial LCA databases, e.g. GaBi or ecoinvent, for collecting emission factors.

A diverse product portfolio can significantly complicate the application of the product related accounting since conducting an LCA study for every product is a work intensive process. This challenge can be avoided by

[3] In this case the cradle-to-gate system boundary refers to the extraction and production of purchased materials and goods. Transportation, packaging and supporting activities shouldn't be included

applying the meta-product approach introduced by Mila I Canals (Milà I Canals *et al.*, 2011). It implies clustering all products and setting up an average non-existing meta-product for each cluster. For each meta-product the average features, e.g. materials used in assembly, use phase and EoL scenario, are set up based on the products included in the cluster. Then an LCA study is conducted for each meta-product. Thereby, to calculate impacts on the organizational level, the category indicator results of the meta-products are multiplied with the number of produced products within each product cluster. This approach simplifies data collection process, nevertheless it can significantly increase uncertainty of the results, especially in case of a heterogeneous product portfolio.

2.2 Process based accounting method

The process based accounting can be applied for the most indirect activities. This approach uses activity data on the process level as mass and energy flows, e.g. amount of energy used or waste produced, which is then multiplied with the emission factors. This is suitable in particular for the activities, which do not directly relate to products, e.g. business trips, waste generated and employees commuting. However, it is less practical for *processing, use* and *EoL of sold products,* because for these activities the inventory data is usually not available on the process level (as mass and energy flows), but on the product level (e.g. amount of sold products).

For the quantification of *procurement* and *supporting activities* the amount of raw materials, goods and services purchased represents activity data and should be applied in combination with the cradle-to-gate emission factors. For calculation of *supporting activities* potential limitations may arise due to lower availability of emission factors. For example, such processes as consulting or maintenance services are often not available, especially in public databases.

The upstream activity *purchased energy* can be calculated using the amount of fuels or electricity consumed as activity data and the cradle-to-gate fuel or electricity mix specific emission factors. For the process based accounting of the activity *waste generated* the amount of produced waste classified by type (e.g. metal scrap, industrial waste, hazardous waste) serves as activity data. Applied emission factors have to be waste type and waste treatment specific and represent the direct impacts of the treatment companies per one unit (e.g. ton) of a specific type of waste. For both activities activity data is usually good available, since its collection is required by the environmental management systems standard ISO 14001 (ISO, 2015), which is adopted by many organizations. Emission factors for energy consumption related processes and waste treatment processes are available in public databases.

The quantification of *upstream* and *downstream transportation* is carried out by using either fuel specific or transport mode specific emission factors. The fuel specific emission factors represent impact per combustion of one unit of fuel, e.g. kg CO_2e per one litre of diesel. Thus, the amount of fuel differentiated by fuel type has to be applied as activity data. The transport mode specific emission factors represent the impacts per km or passenger-km for a specific transport type, e.g. kg CO_2e/ passenger-km by train. The distance travelled differentiated by transport type has to be applied as activity data. In both cases the emission factors represent the impact of the 1st tier supplier direct processes. Limitations in the method application can arise due to missing activity data since information about fuel consumption needs to be collected from suppliers.

The calculation of the activities *leased assets* and downstream *leased assets, franchise and investments* doesn't have a standard process based approach and thus is not addressed in this section. Recommendations for the application of the process based accounting are shown in Fig4.

2.3 Monetary based accounting method

The monetary based accounting bases on the environmentally extended input output (EEIO) analysis. It connects economic flows between different industries with environmental burden caused by this industries and allows calculating total upstream environmental impacts associated with production of one monetary unit output in a specific industrial sector (Suh and Huppes, 2005; Kitzes, 2013; Kjaer *et al.*, 2015). The monetary based emission factors represent the cradle-to-gate emission per one monetary unit spent on a product (kg CO_2e/1 EUR), are sector-specific and often differentiated by country. The calculation is carried out by multiplying expenditures of the reporting company for specific raw materials (e.g. steel), intermediate goods (e.g. machinery) and services (e.g. cleaning) with the monetary based emission factors of the corresponding industrial sector.

The method can be applied to all indirect activities for which expenditures as activity data are available. This is applicable for all upstream activities except *employee commuting* since the company pays for purchased materials (*procurement*), services and capital equipment (*supporting activities*), business trips and transportation of materials. The activity *downstream transportation* can also be quantified using the monetary based accounting when the reporting company pays for the transportation of its products to customers.

To calculate impacts in the activity *procurement*, expenditures E for all purchased goods during the reference period are multiplied by the monetary based emission factor F of the industry sector i in country c (where products were produced) and then summed up over all industry sectors and countries these goods where purchased from (eq. 3).

$$Procurement = \sum_i \sum_c E_c^i * F_c^i \quad \text{(Equation 3)}$$

The monetary based emission factors can be calculated according to the methodology of the environmentally extended input output (EEIO) analysis which uses input-output (I-O) tables with environmental extensions (Kitzes, 2013). A number of databases, e.g. EXIOBASE (Tukker *et al.*, 2013) and EORA (Lenzen *et al.*, 2013), are built up on the multi-regional input-output models and, thus, provide country specific datasets.
As described in section 2, for some activities only the emissions of the 1st tier supplier's direct processes have to be accounted for. In this case, the emission factors can be calculated by dividing the total annual impacts B (environmental extensions) of an industry sector i by its total monetary output X (eq. 4)[4].

$$f^i = \frac{B^i}{X^i} \quad \text{(Equation 4)}$$

As described in section 1, *processing of sold products* is one of the most challenging activities to quantify due to poor data availability and a very time-intensive data collection process. Nevertheless, for many companies this activity significantly contributes to the indirect impacts. For the calculation the emission factors of the 1st tier supplier's direct processes have to be applied. The latter can be calculated as shown in eq. 4 for the industry

[4] For more information on EEIO analysis see (Kitzes, 2013)

sector the reporting company's customers belong to (e.g. Machinery, Electrical and Optical Equipment). In case customers belong to different industries, an average or weighted average emission factor of the industry sectors can be calculated. Weighting can be performed e.g. based on the share of products sold to each customer. The activity data required for the calculation represents monetary output of the customer allocated to the reporting company. This data is generally not available, but can be estimated using the input-output tables. For this purpose, data regarding the value of the products sold by the reporting company during the reference period and the output creation of the customer per one unit input are needed. The value of the products sold by the reporting company can be determined as the company's turnover. The output creation factor (*OCF)* of an industry sector *i* can be calculated using the input-output tables by dividing the *total output* by the *total intermediate input* of this sector (eq. 5). The output creation factor should be calculated for the sector the customers belong to. In case the customers belong to different industry sectors, the value creation factor can be calculated as the weighted average of different industries.

$$OCF^i = \frac{total\ output^{\ i}}{total\ intermediate\ input^i} \quad \text{(Equation 5)}$$

The impact quantification is performed by multiplying the turnover *T* of the reporting company *RC* with the output creation factor *OCF* of its customer *C* and the emission factor *f* of its customer (eq. 6).

$$Processing\ of\ sold\ products = T^{RC} * OCF^C * f^C \quad \text{(Equation 6)}$$

The recommendations for the application of the monetary based accounting are provided in Fig5. The accuracy of the results is restricted by the limitations of the EEIO analysis including low sector resolution, price homogeneity and linear models (Suh, 2006; Wiedmann, 2009; Kitzes, 2013; Piñero *et al.*, 2015). Due to these shortcomings the monetary based accounting is recommended only as a screening method (WRI and WBCSD, 2011; UNEP, 2015).

3 Hybrid approach

Based on the recommendations for application of the product related, process based and monetary based accounting described in section 2, this section demonstrates how these methods can be linked within the hybrid approach.

The framework for the hybrid approach is presented in table 2. It represents a matrix with the summary of the recommendations for using a calculation method for the quantification of each indirect activity and provides an overview of the activity data and emission factors required. The table addresses the methods which best suit for the quantification of an activity based on the sections 2.1-2.3. The cells of the table are remained empty in case the accounting pathway does not cover the whole activity or the data collection process is very work-intensive, which does not mean that the method is not applicable for the activity. For example, the product related accounting is not recommended for the activities *waste generated*, *upstream transportation* and *supporting activities*. As described in section 2.1, although the product LCA case studies may include these processes, on the organizational level these activities also consider further not product related processes, e.g. canteen waste or transportation of the office furniture. In that case, practitioners need to quantify these processes additionally using the process based or monetary based accounting. This leads to additional working effort.

As shown in table 2, for the most activities more than one calculation method can be applied. For the indirect activities *procurement* and *downstream transportation* practitioners can choose between all three approaches. For the *use and EoL of sold products* only the product related accounting is recommended. For all other activities two approaches are applicable. In the following, selection of the methods and potential limitations are described.

The product related accounting best suits for quantification of the activities *procurement, downstream transportation, processing of sold products, use* and *EoL of sold products* and can be utilised after the reporting company has conducted LCA studies of its products. The activity data representing number of produced and sold products is mostly available internally in the reporting company. The emission factors have to be collected from the product LCA studies. As described in section 2.1, setting up representative or meta-products significantly facilitates application of the method, but may also raise uncertainty especially for the companies with a diverse product portfolio.

The process based accounting can be used to calculate impacts for the most indirect activities. Activity data has to be collected internally (e.g. for the activities *procurement*, *supporting activities*, *purchased energy*, *waste generated*) or from external sources (e.g. for *transportation*). Emission factors can be collected from external databases and statistical data, whereas their availability in freely accessible databases may be limited especially for *supporting activities*.

The monetary based accounting can be applied for the most indirect activities as well. The activity data is represented by expenditures for goods and services and can be collected internally. The cradle-to-gate emission factors or the emission factors of the 1st tier supplier's direct processes can be quantified using I-O tables with environmental extensions.

The hybrid approach allows flexibly choosing an accounting method depending on the data availability without leaving relevant indirect activities unconsidered. When aiming at a more robust calculation, either product related or process based accounting should be used. The process based and product related accounting methods are built on the mass and energy flows and use same physical models as source for the emission factors. While the process based method implies the top-down data collection, e.g. mass of all materials purchased in the reference year, the product related method is carried out bottom-up from the product level. Although, as mentioned before, both methods base on same physical models, the resolution of the activity data may be higher on a product level (bottom-up) than on a company level (top-down). For example, while on organizational level "plastics" might be one material flow, on a product level different plastic types are usually considered. For that reason, the product related accounting might be more robust than the process based, since more specific emission factors may be used. In contrast, the monetary based accounting relies on the economic interrelations and is generally considered as less precise due to the limitations of the input-output analysis. The sector aggregation, e.g. when assigning all purchased metals to the sector *basic metals and fabricated metal products*, no distinction is made between different metal types. Therefore, we do not recommend to use the monetary based accounting when a robust quantification is desired and the data for other methods is available. Nevertheless, since the monetary based accounting relies on the financial information, activity data is usually good available and easy to collect. Furthermore, the emission factors can be calculated using the input-output tables, so that the reporting organization does not need to access commercials LCA databases. For this reasons the monetary based accounting can be seen as a good method for the companies in the first year of reporting. Besides, it can be applied when practitioners aim at a more unified calculation for the most activities, instead of combining it with the two other methods.

The hybrid approach enhances implementation of the life cycle perspective on the organizational level. By making the exact data need transparent for each accounting method, the hybrid approach allows switching from a less robust (monetary based) to a more comprehensive calculation (product related or process based) after the company gained more experience or got better access to relevant databases. This is of high relevance for small and medium organizations and companies in the first year of reporting, which usually do not have access to commercial LCA databases and thus are confronted with lack of appropriate data.

4. Case study

4.1 Method

To evaluate the feasibility of the introduced approach, it is applied to quantify indirect impacts of the company Brose Fahrzeugteile GmbH & Co.KG (in following referred to as Brose). Brose is the world's fifth largest automotive supplier with headquarter in Coburg, Germany, and more than 60 production plants in 23 different countries. The company's product portfolio consists of intermediate vehicle components and is divided into four business units: door systems, seat systems, closure systems, and drivers.

So far GHG emissions of direct and indirect activities associated with purchased energy are evaluated annually in accordance to the GHG Corporate Protocol Corporate Accounting and Reporting Standard (WRI and WBCSD, 2004). The evaluation of further indirect activities was carried out first time with the overall goal to identify hotspots within the organization's value chain and track environmental performance over the next years. The data availability for emission factors was restricted to public freely accessible datasets, since no commercial LCA databases were used in the company. Six upstream activities (*procurement, supporting activities*, *waste generated*, *business travel*, *employee commuting*, *transportation*) and four downstream activities (*transportation*, *processing*, *use phase* and *EoL treatment of sold products*) were evaluated as relevant[5].

The application of the hybrid approach for compiling inventory is presented in table 2. The organization aimed at a more robust calculation, thus, application of the product related or process based accounting was preferred. The company has internal product LCA studies including evaluation of the cradle-to-gate and use phase impacts. On this basis, product related accounting was carried out for the activities *procurement* and *use phase of sold products*. The latter was quantified for a use phase of 200.000 km, which is standard lifetime of a car in the LCA studies of the company's customers. The product LCA studies consistently included only the category indicator results for global warming potential (GWP), therefore only the impact category climate change was quantified. The product related accounting was also selected for the activity *EoL of sold products* based on the products' recyclability and recoverability data and process based emission factors for the waste treatment. The process based accounting was selected for the activities *waste generated* and *employee commuting*. Emission factors were collected from the freely accessible database DEFRA (DECC and DEFRA, 2012). Since only the GWP factors were available, the calculation was limited to the impact category climate change. Applying this method

[5] The relevance was determined based on the following criteria: expenditures, expected impacts based on the results of the internal LCA studies and literature data

for the quantification of *upstream* and *downstream transportation* and *business travel* was not possible due to missing activity data. For *supporting activities* the emission factors could not be collected because relevant goods (e.g. intermediate machinery components, cleaning agents, consulting and maintenance services) are not explicitly available in public databases. Furthermore, some activity data was not available, e.g. for cleaning and maintenance services. For these activities and for *processing of sold products* the monetary based accounting was determined. Monetary based emission factors were calculated using the multiregional input-output table with environmental extensions provided by World Input Output Database (WIOD) for the impact categories climate change and acidification as well as for water use. The monetary based emission factors (AP and water use) were applied to the activity *procurement* as well (see table 2). Application of the hybrid approach to the company's value chain is also demonstrated in Fig6.

The meta-product approach was applied to compile the inventory data usind the product related accounting. The meta-product characteristics including weight, cradle-to-gate and use phase category indicator results as well as recyclability and recoverability were established using existing LCA studies of Brose products. The inventory for the bottom-up accounting included 13 meta-products for the business unit *seat* systems (for 112 actual products), 38 meta-products for the business unit *door systems* (for 121 actual products), two meta-products for the business unit *closure systems* (for 31 actual products) and three meta-products for the business unit *drivers* (for eight actual products).

4.2 Results

An overall result for the entire company can only be provided for the impact category climate change, since only the GWP factors were available consistently for all calculation methods. This can be explained by the fact that process based emission factors in the free of charge public databases were limited to GWP, while environmental extensions applied for the monetary based calculation contained data for further impacts (e.g. water use and acidification).

The highest impacts in the category climate change are driven by the *use phase of sold products* (92% of the total company's indirect GHG emissions) and the second largest impacts arise from *procurement (6,6%)*. The remaining indirect activities contribute to less than 2% of the total impact, whereas the highest emissions are caused by *processing of sold products* followed by *up- and downstream transportation*. Impacts of the activities associated with employees' transportation (*business trips* and *employee commuting*) and waste treatment related processes (*waste generated* and *EoL of sold products*) are marginal compared to other activities (see Fig7). The total indirect impact of Brose in the category climate change sums up to more than 31.787 kilotons (kT) CO_2e. The quantification of all considered impact categories (climate change, acidification, water use) was possible for the activities *procurement*, *supporting processes*, *capital goods*, *business trips*, *transportation* (up- and downstream) and *processing of sold products*. For these activities, the results sum up to 5,8 tons SO_2-equivalents and 950 million m^3 water use. The results are presented in Fig8.

5. Discussion

5.1 Case study

Applying hybrid approach allowed to quantify all relevant indirect activities on the organizational level. Using different accounting methods helped to bypass data limitations and foster the calculation process. Nevertheless, only the impact category climate change could be quantified for all relevant activities. This means that identified hotspots in the value chain are based on the single indicator and, thus, do not reflect the environmental performance of the company completely. For this reason, it is crucial to consider potential shifting of the environmental burden to other impact categories when interpreting the results. For six out of ten relevant activities AP and water use were also calculated. These impact categories were quantified by means of monetary based accounting, but could not be calculated using product related or process based accounting, because the reporting organization did not have access to corresponding emission factors. The case study demonstrates that non-availability of the emission factors besides GWP is a significant limitation for companies that do not have access to commercial LCA databases and aim at conducting an OLCA study. As demonstrated in the Guidance on Organizational Life Cycle Assessment, emission factors for the indirect activities can be collected as direct emission data at the supplier level, from the suppliers' LCA studies or generic databases (UNEP, 2015). Nevertheless, currently most companies are not able to provide this information to their clients, so that generic datasets from commercial databases has to be used. Therefore, we would like to emphasize that making emission databases publicly available can significantly promote implementation of the organizational LCA. In the following, each of the applied methods is discussed.

Availability of product LCA studies allowed quantifying activities *procurement*, *use phase* and *EoL of sold products*. Apart from the limitation to the GWP category indicator results, the method allowed a straightforward calculation using the meta-product approach. Nevertheless, the representativeness of the meta-products needs to be checked and, if necessarily, further meta-products have to be established. For example, the product cluster *seat systems* includes 121 different products, but is characterized by only 13 meta-products. The OLCA results demonstrated that *seat systems* account for about half of impacts in the activity *procurement* and one third of the impacts in *use phase of sold products*. Therefore, establishing more meta-products for this cluster can significantly raise accuracy of the results. This applies also for *drivers*. This product cluster contributes to more than 50% of the impact in the activity *use of sold products*, but is represented by only two meta-products.

Application of the process based accounting was limited to *waste generated* and *employee commuting.* Apart from these activities, either activity data (for *supporting activities*, *up*- and *downstream transportation*, *business travel*) or emission factors (for cleaning and maintenance services within *supporting activities*) were lacking.

The monetary based accounting was used to calculate five indirect activities: *supporting activities*, *business trips*, *processing of sold products*, *upstream* and *downstream transportation*. After the emission factors were calculated by means of I-O analyses, the quantification of impacts was carried out using the financial activity data. Due to the high sector aggregation of the I-O table, activity data was also grouped according to the I-O sectors. For example, a broad range of products including soldering materials, oil and grease, adhesives, and coatings were assigned to the sector "*Chemicals and Chemical Products*". Such aggregation could raise uncertainty of the results, as the impacts of products listed above significantly vary. Apart from that, the environmental extensions of the WIOD database do not provide data for water use for the sector "transport equipment". Therefore, water use is zero in the activity *processing of sold products* (see Fig8). These results are questionable since water is used for example for automotive painting.

To compare outcomes of the calculation methods within the introduced hybrid approach, the results provided by the product related and monetary based accounting carried out in the case study for the activity *procurement* were compared. According to the product related accounting, the impact is 2.112 kT CO_2e, according to the monetary based accounting 895 kT CO_2e. Thus, the monetary based accounting provided result about 2,4 times lower than the product related accounting. This can be explained by the strong aggregation of the industry sectors in the input-output table compared to the LCA studies. While the inventory data of the product LCA studies carried out in the company has high level of detail (e.g. up to 20 different plastic types), the monetary based accounting bases on the strongly aggregated data, e.g. one industry sector "plastics and rubber". This demonstrates that interpreting and comparing results (e.g. for identification of hotspots in the value chain) calculated with different methods should be done with caution, since lower or higher impacts might be influenced by the methodological bias and not the activity as such. Therefore, on the one hand, using different sources helps to bypass difficulties in data collection, but, on the other hand, may lead to discrepancy of the results as demonstrated above. This applies also to the emission factors for the product related and process based accounting, which originate from the company's internal LCA studies (product related method) and the database provided by the Department for Environment, Food and Rural Affairs (DEFRA) of UK (DECC and DEFRA, 2012) (process based method). The latter was used to calculate two activities: employee commuting and generated waste. Although the emission factors provided in the DEFRA database are representative for the European Union (where the most company's production sites are located), their applicability for the sites in North America and Asia should be checked. Such inconsistencies need to be considered when identifying hotspots in the supply chain. For example, activities "employee commuting" and "generated waste", both calculated with the process based accounting, have lower impacts compared to "supporting activities" and "transportation" (monetary based accounting) (see Fig7). In this case, the effect of the applied emission factors should be investigated.

The case study demonstrated feasibility of using the hybrid approach for conducting an O-LCA study. Despite the incomplete scope (only the GWP is calculated for all activities), it creates a solid basis towards a more comprehensive environmental assessment in the next years through including further impact categories. The results identify the hotspots in the value chain. For a more detailed analysis, consistent data sources for the emission factors need to be applied.

5.2 Hybrid approach

The hybrid approach introduced in this paper allows choosing between different calculation methods depending on availability of activity data and emission factors. This can significantly facilitate the process of compiling the inventory data, in particular for small and medium enterprises and companies in the first year of reporting. The latter usually do not have access to commercial LCA databases and, thus, are confronted with lack of data. Besides, smaller companies usually have very limited working capacity to conduct an OLCA study and therefore strive for a time-efficient calculation procedure. Each accounting method has some limitations, which should be considered when applying the hybrid approach. Apart from that, the hybridization as such can lead to methodological errors, e.g. double counting or cut offs. These and other limitations are discussed below.

Several companies use LCA to analyse environmental performance of their products. For this reason, product related accounting can often be easily applied, since the activity data (number of produced and sold products) can be collected internally and the category indicator results are then available in the already existing product LCA studies. In this case, the accuracy of the results directly depends on the accuracy of the product LCA studies, thus, good data quality used for calculation of the category indicator results has to be ensured. Using the concept of meta-products significantly facilitates method application. Nevertheless, it may cause bias of results, when divergent products are grouped into one cluster. Therefore, sufficient number of meta-products have to be ensured.

With regard to the activity *use phase of sold products*, two calculation pathways exist. The flow based approach considers all products produced in the reference year and their whole use phase (as demonstrated in the case study). The stock based approach calculates impacts of all products produced in the previous years, but considers their use only during the reference year. Both approaches meet the ISO 14072 requirements to include "use stage emissions of sold products over their expected lifetime". Nevertheless, collecting activity data for all products of the previous years might be challenging, e.g. when an organization was restructured. Still, the stock based approach might be advantageous when accounting impacts of capital equipment, e.g. machinery and buildings. In that case, spreading the impacts over the years helps to avoid the distortion of the results in the year when the equipment was procured.

The issue of the reference year is also important for the calculation of the activity *procurement* by means of the product related accounting. In O-LCA, the reference year is usually one year, while in product LCA studies it includes the whole product's lifetime, which is usually longer than one year. Thus, raw materials or intermediate products purchased by the reporting organization might have been produced in the previous years. Nevertheless, within O-LCA calculation, the impacts caused by the extraction and manufacturing of these products will be accounted in the year when the reporting company purchased them. This may lead to different results, because of the inter-annually variability of some the characterization factors (e.g. increasing water scarcity).

The process based accounting fits well for the most activities from the methodological point of view. As described above, for small and medium enterprises and companies in the first year of reporting it might be challenging to gather further emission factors apart from GWP. Nevertheless, even if the emission factors are available, application of the method might be restricted due to missing activity data. This relates in particular to the transportation activities, e.g. *up*- and *downstream transportation* and *business travel*. The calculation requires either the information on the fuel spent during the transportation or the distance travelled. Gathering this data from the suppliers is very challenging, and even it was collected, further difficulties, e.g. allocation between transportation of other company's goods, may hinder the calculation.

The monetary based accounting is recommended only as a screening method due to the limitations described in section 2.3. Nevertheless, it can serve as an alternative calculation method for companies that cannot apply other methods due to limitations in data availability. The method is relevant in particular for *supporting activities*: the high amount of different materials, intermediate products and services significantly complicates gathering emission factors. As described above, application of other methods for the transportation activities (*up*- and *downstream transportation* and *business trips*) can be restricted due to missing activity data. The monetary based accounting can thereby help to bypass this challenge.

The problem of double counting due to partially overlapping system boundaries when connecting the process and input-output based methods for the inventories on a product level is addressed by several authors (Suh *et al.*, 2004; Strømman, 2009; Strømman, Peters and Hertwich, 2009). This problem remains relevant also on the organizational level. As described above, some product LCA studies may include, for example, transportation or processes that belong to *supporting activities*. This should be checked to avoid considering these processes twice. The systematic truncation error is relevant for the process based and product related accounting, since both methods rely upon the process flow diagram with a set up system boundary. Another factor, which can significantly influence the results, is the data resolution. This is relevant in particular for the monetary based accounting, which requires aggregating activity data to the resolution of the industrial sectors in the I-O table used for the calculation. The data granularity problem may also apply for the process based accounting, because when collecting activity data top-down, e.g. for *procurement*, it might be grouped as metals, plastics etc. Disaggregating this data is possible, but requires additional working effort. In such a case, the product related accounting is more advantageous, because product LCA studies are usually carried out using detailed inventories.

Conclusions

Quantifying impacts in the organizations' value chain gains importance and becomes a part of the environmental impact evaluation for several companies. However, the resource intensive data collection process needed for conducting the inventory analysis can discourage LCA practitioners from conducting an OLCA study. To support companies in facing these challenges, a hybrid approach for the quantification of indirect activities on the organizational level is presented in this paper.

The introduced framework recommends the accounting method(s) for each indirect activity, which suits best for the quantification based on the system boundary requirements and data availability. The introduced hybrid approach allows companies to choose the most adequate calculation method for every indirect activity depending on the data available. Thus, a company specific calculation pathway can be established serving its particular requirements and capacity for collecting data and quantification. The approach can be adopted for both small organizations and multi-national corporations. It is particularly relevant for companies in the first year of reporting that do not have a comprehensive emission database internally or access to commercial datasets.

The limitations of connecting different accounting methods for one inventory, e.g. double counting, should be taken into account when interpreting the results. Although hybrid approach serves well for the identification of the hotspots in the value chain, for a detailed analysis applying one accounting method, either process based or product related, might be more advantageous due to lower uncertainty compared with the monetary based accounting.

Availability of emission factors plays a key role for performing a comprehensive and robust assessment. While there are many publicly accessible databases providing GHG factors, emission factors for other impact categories are often available only in commercial datasets. As demonstrated in the current study, for some companies this can be a significant obstacle to conduct a complete OLCA study and lead to either disregarding some activities or calculating only the impact category climate change. In both cases, there is the threat that the decision-makers induce actions that rather shift environmental burden between impact categories or activities than improve the whole environmental performance of the company. Therefore, providing more freely accessible and robust LCA databases is essential to emphasize further evaluation of impacts on the organizational level under life cycle perspective and foster the dissemination of the LCA methodology.

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TABLES

Table 1. System boundary requirements for the emission factors (based on WRI and WBCSD (2011))

System boundary	Upstream activities	Downstream activities
Cradle-to-gate	Procurement	
	Supporting activities	
	Purchased energy	

Direct processes of the 1st tier supplier	Transportation	
	Waste generated	
	Business travel	
	Employee commuting	
	Assets leased	
		Transportation
		Processing of sold products
		Downstream assets
		End of Life of sold products
Impacts over the whole use phase		Use of sold products

Table 2. Application of the hybrid approach. The rows represent the activities on the organizational level and the columns include the data needed to quantify the activities using a specific accounting method; the cell is empty if a method is not (well) applicable for an activity. The cradle-to-gate emission factors refer to the upstream processes (until the entry gate of the reporting organization). Bold text indicates the method used in the case study.

	PRODUCT RELATED		PROCESS BASED		MONETARY BASED	
Activity	**Activity data**	**Emission factor**	**Activity data**	**Emission factor**	**Activity data**	**Emission factor**
Procurement[6]	**Number of produced products**	**Cradle-to-gate category indicator result of the product LCA [GWP]**	Amount of purchased goods and materials (direct procurement)	Cradle-to-gate (excluding packaging and transportation) per unit (e.g. mass/volume) of purchased material	**Expenditures on purchased goods and materials (direct procurement)**	**Cradle-to-gate (based on the EEIO analysis) per monetary unit spent on purchased material [GWP; AP; Water use]**
Supporting activities			Amount of purchased materials, services and goods (indirect procurement)	Cradle-to-gate per unit (e.g. mass/volume) of purchased material/service	**Expenditures on purchased materials, services and goods (indirect procurement)**	**Cradle-to-gate (based on the EEIO analysis) per monetary unit spent on purchased material/service [GWP; AP; Water use]**
Upstream transportation			**Option 1**: fuel or energy spent for the transportation between the 1st tier supplier to the reporting company, differentiated by fuel/energy type	**Option 1**: Emissions of the transportation per fuel or energy unit spent, fuel and energy type specific	**Expenditures on transportation between the 1st tier supplier to the reporting company**	**Emissions of the transportation per monetary unit spent on the transportation between the 1st tier supplier to the reporting company [GWP; AP; Water use]**
			Option 2: distance travelled between the 1st tier supplier to the reporting company, differentiated by transport mode	**Option 2**: Emissions of the transportation per unit of mass (or volume) per km; transport mode specific		
Waste generated			**Amount of produced waste, differentiated by type**	**Emissions of the 1st tier supplier direct processes (waste treatment), waste type and waste treatment specific [GWP]**		

[6] In the case study, the activity *procurement* was calculated using both product related and monetary based accounting.

Business travel			**Option 1**: fuel spent, differentiated by fuel type		**Expenditures on transportation of employees within business trips**	**Emissions of the transportation per monetary unit spent on transportation of employees within business trips [GWP; AP; Water use]**
			Option 2: distance travelled, differentiated by transport mode	**Option 2**: Emissions of the transportation per passenger-km; transport mode specific		
Employee commuting			**Option 1**: fuel spent, differentiated by fuel type	**Option 1**: Emissions of the transportation per fuel or energy unit spent, fuel and energy type specific		
			Option 2: distance travelled, differentiated by transport mode	**Option 2: Emissions of the transportation per passenger-km; transport mode specific [GWP]**		
Downstream transportation	**Number of sold products**	Category indicator result of the product LCA for the transportation from the company to the customer	**Option 1**: fuel or energy spent for the transportation between the 1st tier supplier to the reporting company, differentiated by fuel/energy type	**Option 1**: Emissions of the transportation per fuel or energy unit spent, fuel and energy type specific	**Expenditures on transportation between the reporting company and its customers**	**Emissions of the transportation per monetary unit spent on the transportation between the 1st tier supplier to the reporting company [GWP; AP; Water use]**
			Option 2: distance travelled between the reporting company and its customers, differentiated by transport mode	**Option 2**: Emissions of the transportation per unit of mass (or volume) per km; transport mode specific		
Processing of sold products	Number of sold products	Category indicator result of the product LCA for the processing by the customer			**Turnover of the reporting company, Output Creation Factor of the company's customers**	**Emissions of the reporting company's costumer direct processes (processing) per monetary unit output [GWP; AP; Water use]**
Use of sold products	**Number of sold products**	**Use phase category indicator result of the product LCA [GWP]**				
EoL of sold products	**Option 1**: number of sold products	**Option 1**: EoL phase category indicator result of the product LCA				

	Option 2: number of sold products and product's recycling and recovery rates	**Option 2: process based waste type and waste treatment specific emission factors [GWP]**				

FIGURES

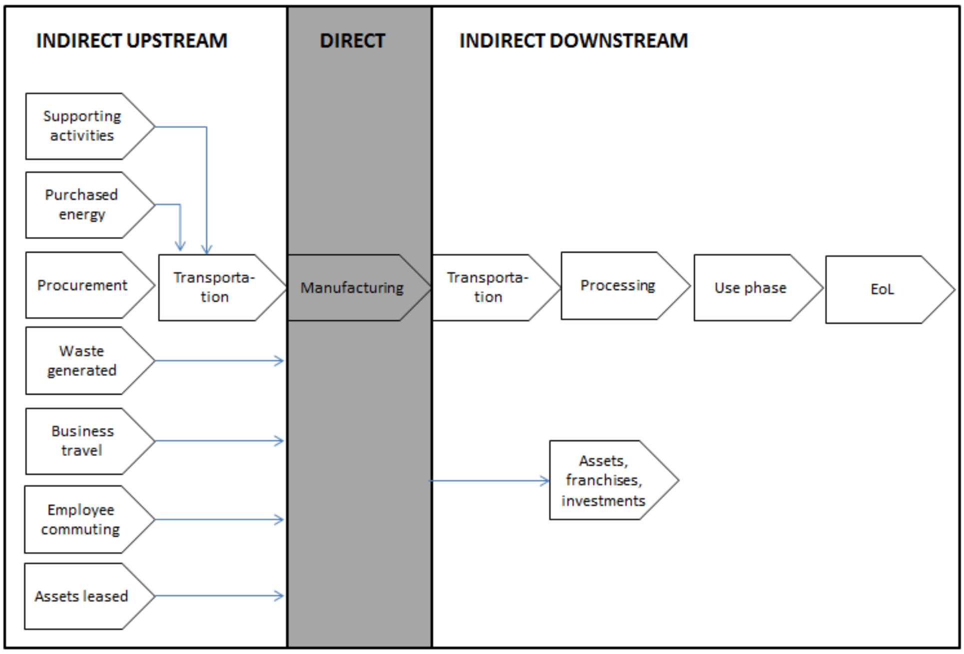

Fig1. Activities on organizational level. Indirect activities are presented in white and direct activities in grey (based on UNEP, 2015)

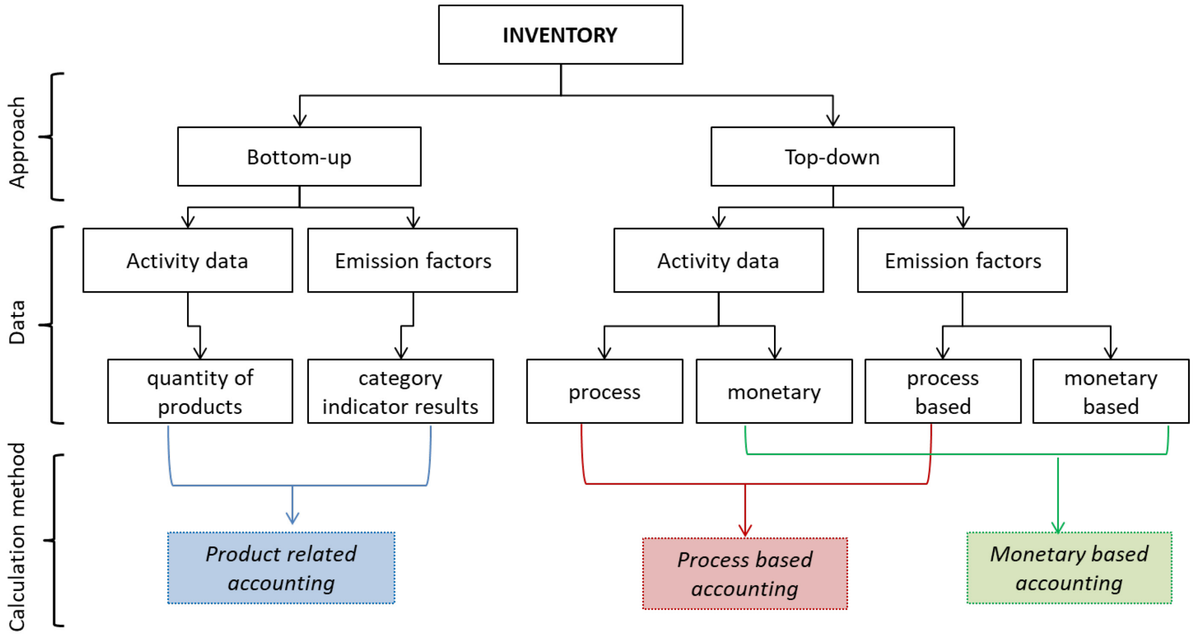

Fig2. Approaches to compile inventory data and corresponding calculation methods for the indirect activities on the organizational level. The colours are introduced to better distinguish between different approaches within the publication

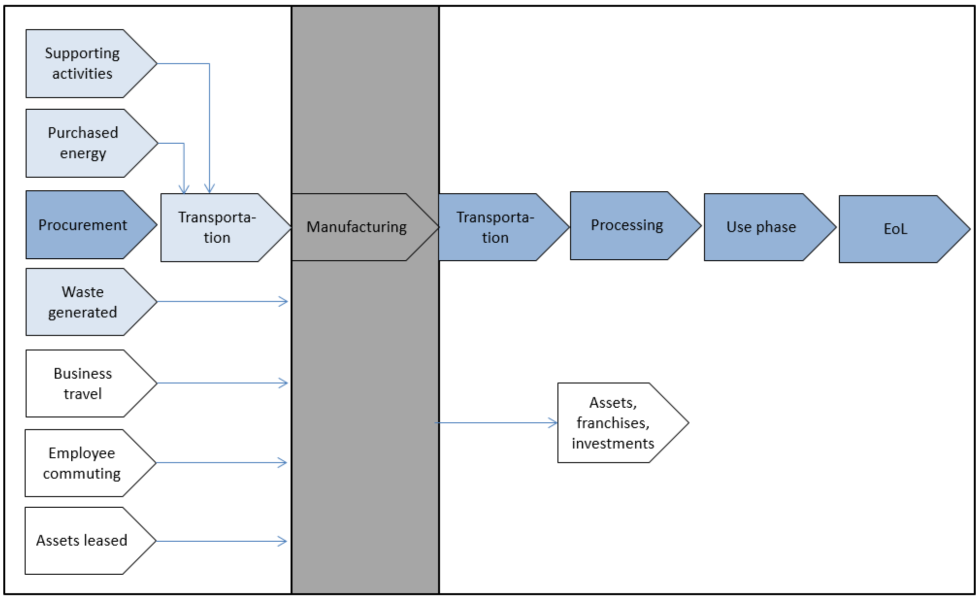

Fig3. Recommendations for the application of the product related accounting method. Blue indicates indirect activities which can be quantified; shaded colours indicate activities which can be partly quantified; white indicates that the method can't be applied; grey refers to the direct activities of the reporting organization

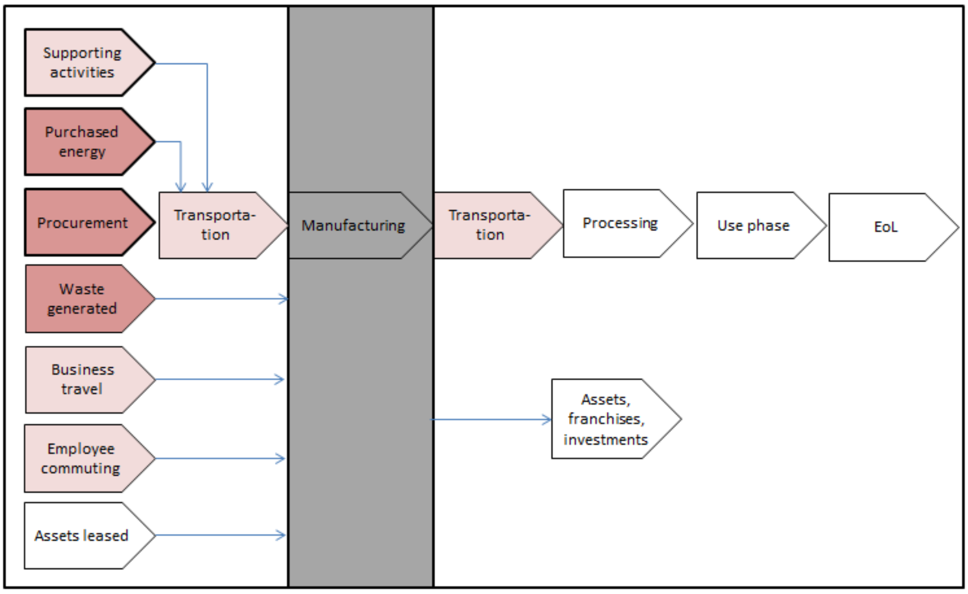

Fig4. Recommendations for the application of the process based accounting method. Red indicates indirect activities which can be quantified; shaded colours indicate activities for which application of the method might be limited due to data availability; bold frames refer to using the cradle-to-gate emission factors; white indicates that the method can't be applied; grey refers to the direct activities of the reporting organization

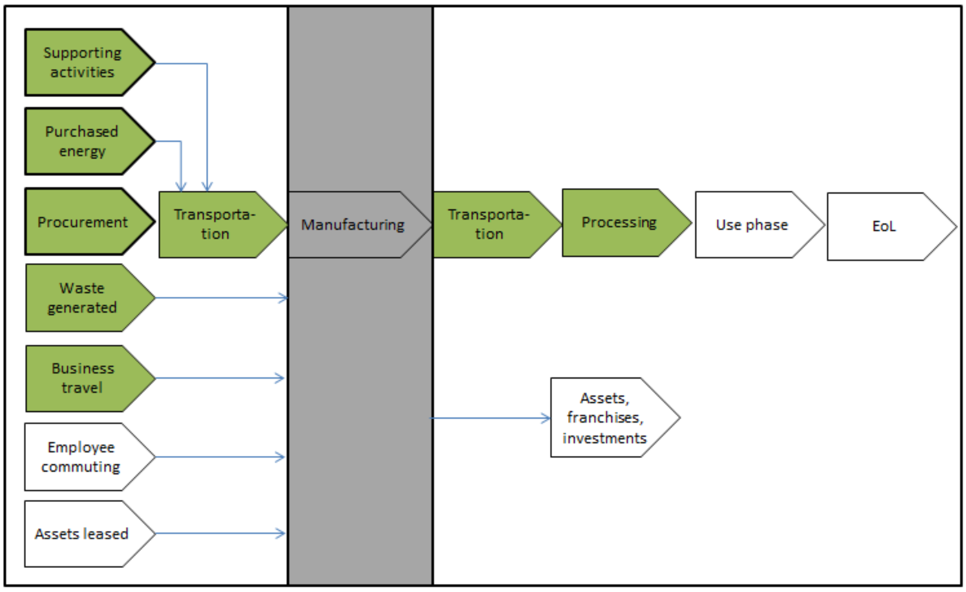

Fig5. Recommendations for the application of the monetary based accounting method. Green indicates indirect activities which can be quantified; bold frames refer to using the cradle-to-gate emission factors; white indicates that the method can't be applied; grey refers to the direct activities of the reporting organization

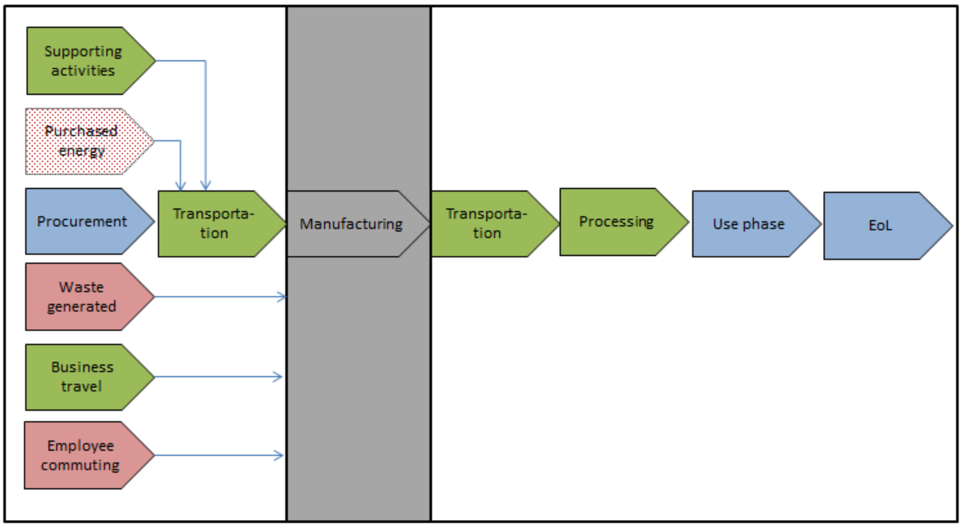

Fig6. Application of the hybrid approach for the calculation of the indirect activities for Brose. Blue indicates product related accounting, red - process based accounting, green - monetary based accounting. Dotted colour refers to the activity purchased energy, which was evaluated using the process based accounting method prior to this study. Grey indicates the company's direct processes

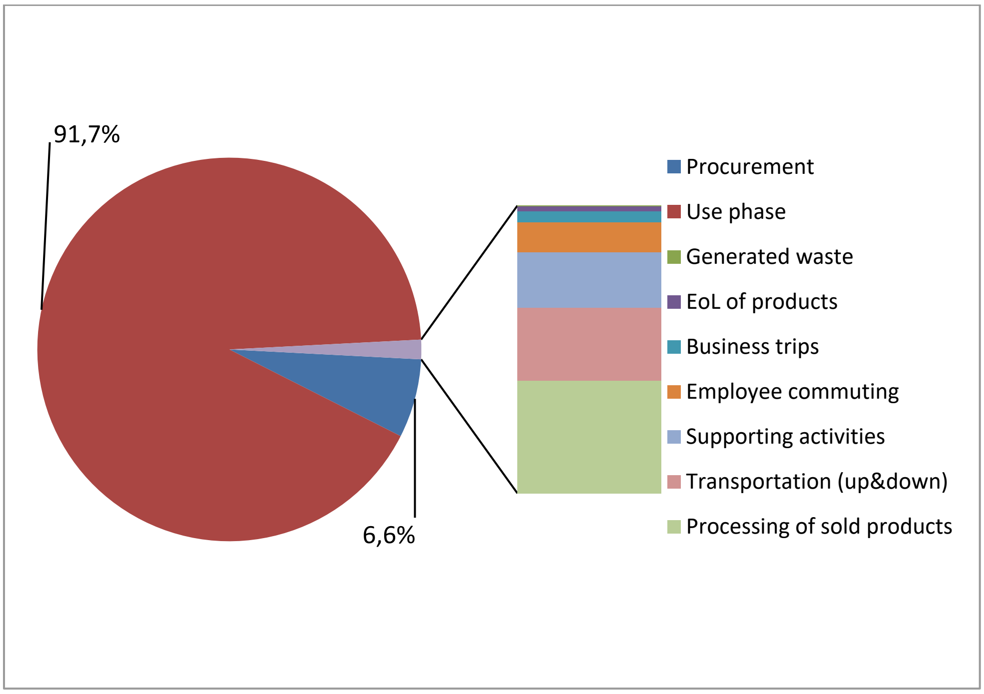

Fig7. Case study results: distribution of impacts in the impact category climate change among all considered indirect activities

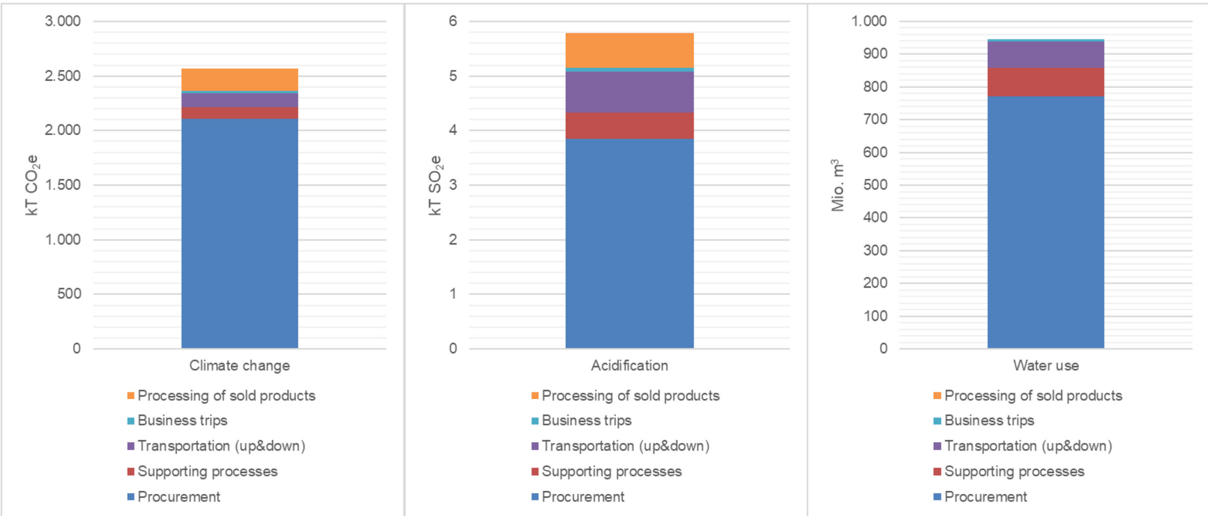

Fig8. Case study results: distribution of impacts in the activities, for which all considered impact categories (climate change, acidification, water use) were assessed