

Carbon footprinting of large product portfolios. Extending the use of Enterprise Resource Planning systems to carbon information management



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ABSTRACT

A number of global brands have committed to reducing carbon emissions and the footprint of their products by certain amounts. Attaining these goals requires that decision makers have timely and detailed carbon information across their product portfolios, and along their production processes and supply chains. However, the number of product carbon footprints in a company is typically limited since it is normally not backed up by an information system for regular carbon data collection and management. Due to their wide availability, Enterprise Resource Planning (ERP) systems represent one promising approach to managing and using carbon information. This research sheds light on the requirements of a comprehensive carbon information management system and discusses the contribution of ERP systems to carbon information management for large product portfolios. To approach the issue, a qualitative analysis of key challenges is conducted based on a case study in a multinational food company. The empirically-supported results provide evidence that large-scale carbon information management covering large product portfolios can be feasible. Feasibility is achieved by re-using existing information assets, thereby increasing the timeliness and accuracy of data and reducing the cost of carbon information generation and use. The paper thus identifies and discusses a set of implications in scaling product carbon footprinting across a company's entire product portfolio by means of ERP systems. The findings propose how the use of ERP systems in carbon information management can improve the overall efficiency and effectiveness of carbon footprinting.

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1. Introduction

Regardless of how much companies have engaged with the challenges resulting from climate change to date, carbon management has become a highly topical area of action due to both opportunities and risks related to it (Hörisch, 2013; Kolk et al., 2008). A survey conducted among 300 global executives shows that managing carbon performance is a topic that can no longer be ignored. Its tangible implications for business require carbon management to be integrated in corporate strategy (Ernst and Young, 2011). Furthermore, managing carbon performance and taking advantage of rising opportunities, requires that decision

makers have available detailed carbon information related to their products, along their production processes and their entire upstream and downstream supply chain (Jensen, 2012; Schaltegger and Csutora, 2012).

Measuring and reporting carbon performance has in turn attracted significant attention of companies (Burritt et al., 2011; Jensen, 2012). The large interest of various stakeholder groups such as customers, regulators, competitors (Kolk et al., 2008) calls for a single, uniform, widely comprehensible and comparable indicator. This has led to the rapid adoption of carbon footprinting (CF), which represents the normalised summation of all recognised greenhouse gases related to the life cycle of a product. Yet, despite its wide adoption, the number of product CF in a company is typically limited due to the associated high information demand (Finkbeiner, 2009). Elaborate information systems for regular data collection and management rarely back up the related CF information demand (Bennett et al., 2013; Burritt et al., 2011).

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Notwithstanding information technology's (IT) potential for approaching the previously identified issues (Hack and Berg, 2014; Sarkis et al., 2013), the tools and the critical role of IT and software support for carbon information management have not been subject to an in-depth investigation. Enterprise Resource Planning (ERP) reveals promising potentials for CF, as it captures business activities throughout the supply chain and production process thus generating information on, among others, materials, quantities and supplier. Despite ERP's practical suitability for approaching the issue (Chofreh et al., 2014), extant literature has barely addressed the use of ERP to support carbon information management (Sarkis et al., 2013).

Identifying and discussing the methodological limitations of CF – such as system boundary definition or allocation issues – from an information management perspective, therefore, enables bridging a gap of significant practical relevance. This paper uses empirical data to analyse the actual contribution of ERP to CF. The issue is approached by seeking an answer to the question: What potentials can be leveraged by using functionality and data available in ERP systems for carbon footprinting of large product portfolios?

The paper is structured as follows: Section 2 frames the research problem in the context of information management. This is done by highlighting the gap between challenges for CF that arise due to its life-cycle assessment (LCA) nature on the one hand and the advantages of the application of software solutions in dealing with these challenges on the other hand. Section 3 presents the research methods and provides background information on the case study company. Section 4 presents and discusses the implications that arise from an information management perspective. Section 5 summarises the analysis and relates it back to the original problem of an effective and efficient carbon information management.

2. Harnessing ERP potentials in carbon footprinting

In order to investigate the potential contribution of ERP systems to improved carbon information management, the following section starts off by highlighting the challenges in carbon information and grouping them in five categories. Subsequently, the issue is approached from the opposite perspective, namely: how ERP is able to support the generation and use of environmental and sustainability information (to which carbon performance can be attributed).

2.1. Carbon information management challenges

Extant literature identifies a number of carbon information management challenges, where boundary selection, allocation as well as data availability and quality are considered among the top three issues (Finkbeiner, 2009; Iacob et al., 2013; Reap et al., 2008). Such challenges arise in those situations in particular, where a large number of processes result in a large variety of products. Hence, this complexity can be described as large product portfolios. In view of large product portfolios McKinnon (2010) identifies five categories of challenges. These are discussed below and expanded to integrate the current status of the discussion.

2.1.1. System boundary issues and scope

The life-cycle thinking of CF implies taking into account the direct on-site impacts in company operations as well as the indirect impacts of the company's supply chain (Wiedmann et al., 2009). Within a company's supply chain defining the start and end points for carbon measurement (system boundaries) can be a challenge (McKinnon, 2010). Major complexity arises for today's businesses due to the length and the ramification of their supply chains. Depending on the industry, the major share of the carbon footprint

often does not result from direct emissions, but from the embodied emissions in the supplies of parts, components, chemicals, and materials (e.g. Lee, 2011; Schaltegger and Csutora, 2012). This further complicates establishing the carbon footprint of products.

The available CF standards such as PAS 2050 and ISO 14067 point to the fact that it is critical to select the boundaries correctly and to include both direct and indirect emissions. However, they provide few practical directions with regard to how a company can collect data on indirect emissions (Schmidt, 2009).

2.1.2. Allocation issues

Ardente and Cellura (2012) identify the allocation of impacts as a crucial methodological issue for CF. Similar to the long-debated allocation models of common and joint costs, the allocation of carbon emissions is not a straightforward task. Allocation can be determined based on various data, such as product weight, dimensions, handling characteristics or a combination of these criteria. Thus, the cumulative effect of emission allocation decisions can be substantial (Weber, 2011).

Although the issues pertaining to the allocation of carbon emissions to certain products or processes have been recognised as such and standards have attempted to address the issue (e.g. Minx et al., 2009), related decisions often remain up to the discretion of decision makers (e.g. Schmidt, 2009). This is due to the multitude of situations that arise in companies and the diverse ways companies choose to capture related information. Typical examples of situations where allocation may seem to be up to the subjective judgement of decision-makers arise in cases comprising multi-functional processes, e.g. where production resources or processes share the same production equipment or warehouse space.

2.1.3. Supply chain variability

Various studies show that the structure of supply chains introduces a significant variability in the product carbon footprint (e.g. Craig et al., 2012). Product supply chains can be subject to frequent change (McKinnon, 2010). Such frequent change has been observed to result, e.g. from a switch of raw material sources or substitution of raw materials, moving production between plants, or agricultural inputs, which require reconfiguration of supply chains according to growing seasons. These changes can have a significant impact on the carbon footprints of individual products. McKinnon (2010, p. 49) expresses his doubt that “companies whose products are subject to such variations will regularly recalculate their products, especially where they have a large product range”.

2.1.4. Scalability

Further challenges arise whenever CF is pursued for larger entities (portfolios, organizations). Whereas estimates can be derived by extrapolating information contained in life-cycle databases, result accuracy unavoidably deteriorates as the secondary data may not reflect reality (Schaltegger, 1997) as they assume that a subset of individual products are representative for a larger product entity. Therefore, enlarging the scope of CF is a key challenge in improving its usability in practice (Ayres and Ayres, 2002). Furthermore, the information provided by different databases is usually not consistent (Tukker and Jansen, 2006). Lack of uniformity in data produced has also been identified as a major limitation (De Haes et al., 2004) which plays an important role when automating and scaling the calculation of CF across a large portfolio of products.

Yet, prior research seems to argue along traditional lines and assumes linear scalability, i.e. the effort increases proportionately to the number of CFs calculated. Only few studies (Meinrenken et al., 2012) have investigated the tools and the critical role of software support and IT in scaling to large product portfolios. Various software tools for generating LCAs such as Gabi, Umberto,

SimaPro have been used to calculate product footprints. Their product-by-product application, however, results in considerable effort when performing CF (Schmidt, 2009). For scaling CF to large portfolios Meinrenken et al. (2012, p. 670 f.) concluded that the two fundamental obstacles that need to be overcome are “required time and expertise” and “lack of uniformity and integrated platform”. Further research converges with this statement (cf. Ayres and Ayres, 2002; Stechemesser and Günther, 2012).

2.1.5. Cost

Additional challenges arise with a large number of products (manufactured in many locations) due to the resource demand (right skills, effort, time) and the related cost (Stechemesser and Günther, 2012). Traditionally, LCAs are calculated in a labour-intensive effort, largely manually and “one product at a time”. Companies with the objective to perform carbon footprinting for a large product portfolio face major obstacles in terms of required time and expertise (Meinrenken et al., 2012). Performing highly disaggregated analysis comprises the collection, validation, and mapping of hundreds of data items per product. This requires expertise and extensive staff hours and is therefore considered a costly undertaking (e.g. Hochschorner and Finnveden, 2003). The problems and costs incurred need to be weighed against the potential benefits (e.g. Reap et al., 2008).

Few approaches have been developed to deal with some of the above issues (Pandey et al., 2010). These deploy various techniques to overcome LCA-related CF limitations for the specific situation in which they are applied. It is important to note, that these limitations are inherent to the process-oriented LCA approach applied in the corporate context as opposed to its input–output counterpart (Minx et al., 2009). Most approaches therefore estimate CF based on the data for each component or process and then consolidate the CF of all components in the product life cycle (cf. Lee, 2011).

One such approach is fast CF (Meinrenken et al., 2012), whereby the resource-intensive LCA is substituted by an approximation. Another alternative to manage the amount and quality of data and the related cost and time necessary for full LCAs include partial LCA methods such as LCA review, matrix approaches and streamlined LCA (Schaltegger and Burritt, 2000, p. 250 f.). These simplified approaches do not represent a generic approach to full CF, but rather overcome certain limitations at the expense of others (Hochschorner and Finnveden, 2003).

To be able to support decision making at the organizational scale (and thus justify related expenses), CF needs to be conducted accurately and be comparable to the real production conditions (Schmidt, 2009). In view of the challenges summarized above, ERP systems appear suitable for addressing large portfolio CF. A number of companies collect “real-life” data by means of ERP systems and therefore have many of the primary data necessary for product-level CF at their disposal. Yet, a review of extant literature reveals that to date ERP has hardly been investigated in view of large-portfolio CF (Sarkis et al., 2013). Therefore, the following subsection discusses the potential relevance of ERP for that purpose.

2.2. ERP in support of carbon footprinting: potentials hardly investigated

For decades the accounting function has been considered the formal and widespread source of information within organizations. Several authors have argued that the mission of accounting information systems has moved from the simple provision of formal and financial information to encompassing a broader range of information (Chenhall, 2003; Scapens and Jazayeri, 2003). The use of ERP technology in particular has facilitated the embodiment of this new vision.

Deploying ERP to manage CF information has been barely discussed to date (Meinrenken et al., 2012; Funk et al., 2009). Yet, attempts have been made to integrate other environmental information in the management information systems of a company. For instance, Fakoya and van der Poll (2013) describe the challenges and benefits of integrating material flow cost information in ERP systems. An earlier attempt to link material flow management and ERP systems has been documented by Jürgens (2002), the focus of his work being on retrieving material flow data from ERP systems.

Modern ERP systems provide effective mechanisms to handle supplier-specific reference data and can distinguish the same input material/component from a different supplier not only regarding monetary valuation (cost) but also regarding its environmental impact (Murphy and Simon, 2002).

Another strength of ERP refers to its analytical capabilities to generate insights for improved decision-making (Holsapple and Sena, 2005). ERP systems capture each business activity as a record with a multitude of data fields containing information about materials, quantities, price, vendor or customer, etc. as well as the date and time of the transaction. This enables a multi-dimensional analysis, e.g. by product, by site, by vendor, by customer, related region and country, and period. Through the use of comprehensive business functionality and detailed logic, ERP systems can flexibly select the best matching reference data to be applied, e.g. for a certain material purchased from a specific supplier and location, using a specific mode of transportation and route.

As Schaltegger and Burritt (2000, p. 253) argue “continuous environmental improvement requires continuous ecological accounting, consisting of relevant and representative information”. Hence, instead of one-off efforts for CFs, it is important to continuously measure the environmental impacts or at least measure them on a regular basis (e.g. monthly). Zapico et al. (2010, p. 705) conclude that there is a significant potential for IT supporting what they described as “metabolism accounting”, i.e. “measuring the environmental impacts in a fast and accurate way [which] provides instant feedback to enable improvements in the flow of energy and materials within the systems”.

Table 1 summarises the challenges for CF from an information management perspective – in accordance with the five categories described in Section 2.1 – and the advantages of deploying ERP in overcoming these challenges.

Given the potential contribution of ERP on the one hand and the identified lack of research on the intersection of CF and IT-support on the other, the remainder of the paper discusses ERP-related considerations in the context of carbon footprinting and derives implications for designing systems that enable large portfolio CF.

3. Research design and methods

The research sought to explore critical factors in initiating carbon footprinting for large product portfolios. The little empirical evidence of corporate practice in the area (as highlighted in Section 2) required that the researchers gain an in-depth understanding of numerous issues arising in the course of a comprehensive design and implementation process. Therefore, a qualitative exploratory research approach was deemed most appropriate.

3.1. Case selection

The exploratory research aimed at gaining an in-depth perspective of the process of developing a system for the regular collection of carbon-related data for both reporting and decision-making purposes. To obtain as much depth as possible, a single case study design was chosen.

The case study company needed to meet a few requirements in

Table 1
Challenges for CF from an information management perspective and the advantages of deploying ERP.

Information management challenges to CF	Related advantages of ERP systems
System boundary	• Ability to define system boundaries • Modelling of organizational and product structures • Transparency on data sources (e.g. LCI databases, ERP) • Availability, maintenance and re-use of master data • Modelling of relevant business processes • Recording of real-life business transactions • Tracking of actual consumption of resources
Allocation issue	• Availability of relevant master data (i.e. emission factors) and transactional data (e.g. production quantities) • Accuracy of primary data of ERP systems based on actual consumption (materials, resources, energy) (Schmidt, 2009) • Regularity and timeliness of carbon information (versus one-off) • Data model allowing for multi-dimensional recording • Data model allowing for multi-dimensional analysis (e.g. by product, by site, by life-cycle phase) • Valuation in multiple dimensions (financial, non-financial)
Supply chain variability	• Calculation method in accordance with established CF standards • Coverage along the global supply chain and company's value chain • Real-time character and automation ensures timeliness of data • Up-to-date information regarding the company's business (organization, supply chain, plants, products, partners, processes) • Information on supply chain partners, business processes, organizational data adaptable to changing realities • Updating and creating new master data (e.g. suppliers, materials) to reflect new realities within the enterprise model • Ability to support audit-trail
Scalability	• Ability to deal with large data sets (i.e. very large number of purchased materials/components, manufactured/sold products, production sites, business partners and locations) • Coverage of entire product portfolio based on real-life data • Uniformity of data structures (De Haes et al., 2004; Meinrenken et al., 2012) • Consistency of data and calculation methods (Meinrenken et al., 2012) • Provide processing speed
Cost	• Replace manual error-prone calculation with automated reliable calculation engine • Re-use of data (master and transactional data) as well as expensive expert LCA data

order to qualify as suitable to attain the research objectives. Thus we looked for a company that

- had a large product portfolio,
- had publicly or otherwise expressed its interest to reduce its carbon emissions,
- had already demonstrated motivation to decrease carbon emissions,
- was looking for an ERP solution to manage the problem,
- was willing to grant access to internal information and dedicate resources to members of the research team.

In addition to a basic description of the company, the following paragraphs describe the extent to which the above criteria were met in the company chosen, Groupe Danone (GD).

GD is among the world's largest companies for fresh dairy products marketed under the corporate name. Other products of high market share include bottled water and baby food. GD generated net sales of €22.4 billion in 2015 (Danone, 2016) and operates in more than 120 countries in Europe, the Americas and Asia: markets that are among the most demanding ones in terms of environmental performance (e.g. Jacobs et al., 2010). The bulk of its production takes place in some 40 countries where GD operates more than 80 country business units (CBU) with approximately 700 sites. The group's portfolio comprises roughly 600 brands with more than 35,000 products, so-called stock-keeping units (SKUs).

The company claims to consider carbon to be a core indicator that will enable it to profoundly and sustainably transform their business practices (Danone, 2012). In 2009, GD made commitments to reduce the carbon footprint of their products by 30% by 2012 across all of its direct business activities related to industrial sites, packaging and transport (Danone, 2012). GD has achieved carbon efficiency of its product portfolio and has reduced its carbon footprint by 35.2% between 2008 and 2012 (Danone, 2013).

The data used in this case study was collected through

interaction with members of the team in charge of setting up and deploying a carbon footprinting system. This setting enabled the authors to collect rich formal and informal information that could not have been gathered by other means. In addition, internal documentation was used. This documentation includes specifications and technical reports. For the purpose of data triangulation, public presentation materials, press articles and corporate reports were collected and evaluated, too.

3.2. Participant observation

Potentially suitable research methods applied in the qualitative research paradigm were screened based on both the purposes of the research and the expected challenges. Among the several potentially suitable data collection methods, we opted for participant observation, which involves social interaction in the field with subjects, direct observation of relevant events, formal and informal interviewing and document evaluation. Furthermore the method accommodates the possibility to adjust the direction the study takes, which was an important consideration, given the little background knowledge available in the area (McCall and Simmons, 1969).

The particular strengths of participant observation and their suitability for achieving our research objectives are manifold. Its main strength, considered essential for achieving the research objectives, lies in the ability to gain a close and intimate familiarity with a given group of individuals and their practices by means of an intensive involvement with the particular group (Symon and Cassell, 1998).

The extended period of interaction with the group studied also enabled researchers to gain sufficient levels of trust among their corporate counterparts (DeWalt and DeWalt, 2010). This was considered advantageous, as internal company information was necessary to understand the decisions behind the carbon footprinting system being developed. Company documents and semi-

structured interviews were used to gather data and subsequently substantiate preliminary findings. During the period between May 2011 and March 2013 a total of 10 site visits and multi-day workshops with key stakeholders took place in Paris to gain an in-depth understanding of the carbon footprinting solution implemented. The regular interaction facilitated data collection in terms of level of detail and accuracy.

The interaction comprised three phases: the first phase between May 2011 and January 2012 had the focus to understand the project status, progress of the international rollout, and the potential for replication. Phase 2 between January 2012 and June 2012 entailed workshops which covered the potential convergence of product carbon footprint and GD's corporate footprint, i.e. using same data basis for both corporate greenhouse gas and product footprint analysis and reporting. The third phase between October 2012 and March 2013 focused on evaluating options to incorporate additional functionality into the ERP system, e.g. the maintenance of emission factors and other footprint rule parameters such as recycling rates or the calculation of additional environmental impact categories like water. Subsequently, key learnings were discussed with company representatives in 2013 and 2014 in order to verify and elaborate the findings. In addition to gaining access to critical information, the participant observation helped recognise critical details, whose intangible nature might conceal them under different research settings (e.g. in expert interviews). Example of such details included the attitude to the topic of carbon footprinting and interactions between the departments involved in the design and implementation of the ERP-based carbon footprinting system.

4. Leveraging ERP systems in large product portfolio carbon management

In the case of GD, the ERP-based product carbon footprint solution sought to enable comprehensive coverage of carbon emissions along the company's value chain. For the purpose of completeness, it covered all product life-cycle phases: from raw materials and packaging through production, storage and distribution, retail, home storage and consumer use to recycling and disposal (Fig. 1). The presentation of the results therefore starts with the issue of specifying the product system defined by its boundaries and follows the logic introduced in Section 2.1.

4.1. System boundary issues and scope

The approach chosen allows calculation of the accumulated

footprint of an SKU based on the footprint of its respective raw materials and packaging materials as they exit the suppliers' gate. This requires that the carbon rucksack of the raw materials and packaging as well as the emissions associated with their transportation from the supplier to the GD production site be considered. For this purpose, information regarding distances and emission factors (EF) for different means of transportation needs to be maintained as part of the GD product footprint system. The same applies to information related to the logistics between GD sites as well as to the retailers' distribution centres. Clearly, the ERP-based product carbon footprint solution has to account for production-related energy use in factories and during storage. In the retail and use phase, the model was required to consider energy used in retail stores. Such country-specific secondary data are gathered from official life-cycle inventory (LCI) databases. Secondary data from LCI databases is combined with primary data from ERP to arrive at country-specific LCI data (e.g. for the impact of cooling at the retailer and at home) with data reflecting what SKUs have been sold and shipped to what market (country). Calculations are done monthly and therefore the appropriate LCI data for the respective period can be drawn on.

It can be implied that in order to support CF, the ERP solution needs to be able to model the product system and to account for business transactions. These include the procurement of components, their consumption and transformation in production, as well as related transportation and the associated environmental impact along the phases of the product life cycle. These systems of record track the activities and store the related data such as quantities consumed and produced, freight payloads, modes of transportation, related distances, etc.

The CF system was also required to be able to perform alternative valuation, i.e. to evaluate activities and their impact beyond monetary terms. This calls for a data model that comprises attributes and metrics such as energy consumption, consumption of resources, and the associated carbon emissions. Combining footprint information with financial cost information can enhance the strategic decision-making process (e.g. [De Benedetto and Klemeš, 2009](#)).

For the purpose of non-financial valuation, a repository of non-financial reference data was considered necessary. These included intensities such as emission factors (EF) but also ratios such as recycling rates or energy consumption per unit of product. These can be secondary data sourced from LCI data bases (e.g. country-specific emission factors for kilogram of a certain substance) as well as based on primary data (such as energy consumption, vendor-specific recipes or also current supplier mix). The use of

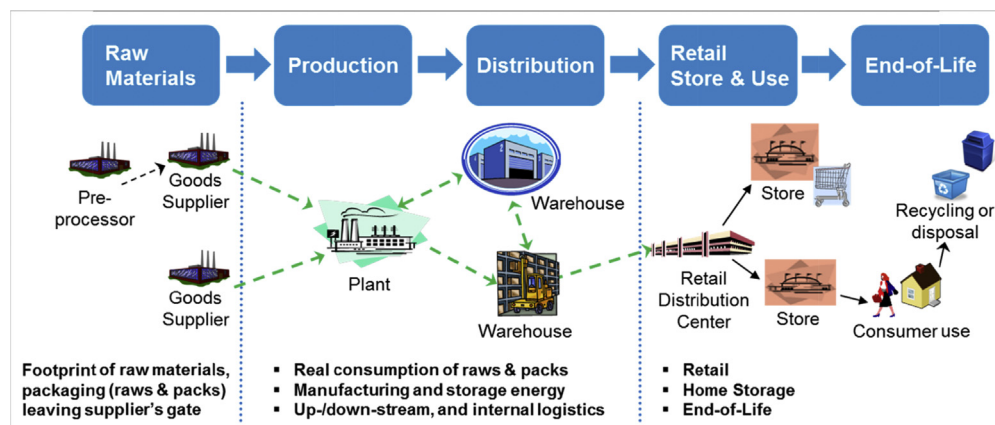


Fig. 1. GD extends the use of ERP systems for implementation of carbon footprinting along the entire product life-cycle (based on [Palmeiro and Cattelain, 2011](#)).

primary data can help to refine the repository of reference data. With the support of ERP systems these data can be calculated specifically to the company being considered and are therefore more accurate than averaged data sourced from LCI databases. Hence, this addresses a limitation regarding the inventory data provided by different databases usually not being consistent (Tukker and Jansen, 2006; Schaltegger, 1997); yet the quantification of the costs and benefits of increased accuracy needs further research.

4.2. Allocation issues

Fig. 2 is a schematic presentation of *GD* product system and emission calculation rules. *GD* distinguishes the EF for different raw materials (1) and packaging by site and accounts for the differences in distance and the mode of transportation. *GD* defines the EF for materials and components based on the substances comprising the materials. Depending on supplier-specific recipes and in combination with the supplier-mix, the “effective” EF for the specific component (raw material or packaging) is calculated. EF for substances are country-specific and their validity is time-dependent. Production (2) leverages data captured from SAP ERP, namely the production orders which contain the volumes (in kg or litre) of the components used to produce the final volume of the SKU. The emission calculation results from multiplication of the production order volume (on the level of the components) with the EF of the respective component. Also considered is inter-company manufacturing (3) which accounts for emissions linked to products that are produced by one country business unit but sold by another country business unit.

The logistics model and the emissions related to transportation/logistics (4) are decomposed by transportation modes (road, train, boat). The EFs are distinguished by transportation mode and sourced from official LCI databases. EF for manufacturing and storage energy consumption (5, 6) are defined by country and can be overridden with a site-specific value, if appropriate (e.g. due to local sourcing of renewables). EFs for retail and home storage (7) were defined by SKU. The volumes shipped are sourced from SAP ERP and derived from “outbound deliveries” in the outbound case and from “production orders” in the inbound case, i.e. what is consumed in production equals what is shipped to *GD* (per month

and site). End-of-life information (8) is distinguished by substance and depends on the country where the product is shipped to, sold and consumed, due to different recycling rates by country.

As exemplified in the case, to perform proper allocation, systems are required that accurately collect and maintain the necessary data to account for the use of different company resources (materials, energy, labour, financial) and the related environmental impact (e.g. emissions) in all business activities. Furthermore, these systems need the ability to perform the established rules of product cost accounting that are used in allocating the financial and environmental impact to the respective product units. By definition, modern ERP systems are designed to accurately account for the consumption of resources and their valuation. With their functionality for financial accounting, materials management, production and other business functions, these systems provide an integrated platform with uniform data structures to meet these requirements (Meinrenken et al., 2012, p. 670 f.). Uniform data structures are the basis for footprinting all products by utilizing the same calculation algorithm.

4.3. Supply chain variability

Given the dynamic nature of managing supply chains, *GD* was observed to face frequent changes in the supply chain – in terms of procurement, production and distribution. Using ERP systems is a means to account accurately for the environmental footprint of a large product portfolio without resorting to averaging, extrapolation or other inaccurate techniques.

In order to leverage and re-use existing information assets to the extent possible, *GD* combines life-cycle analysis with relevant master and transactional data from the existing SAP ERP systems. In fact, 80% of the relevant data is sourced from the existing ERP systems (Danone, 2012, p.37). Changes in the business and the company's supply chain are already captured in the ERP system to reflect business activities as accurately as possible. Building on the schematic presentation of *GD*'s product system, Table 2 describes the relevant data and business documents as well as the data sources used for carbon emission calculation.

Contrary to the arguments brought forward by McKinnon (2010), that businesses are unlikely to account for changes due to variability in production processes and supply chains, real-time ERP

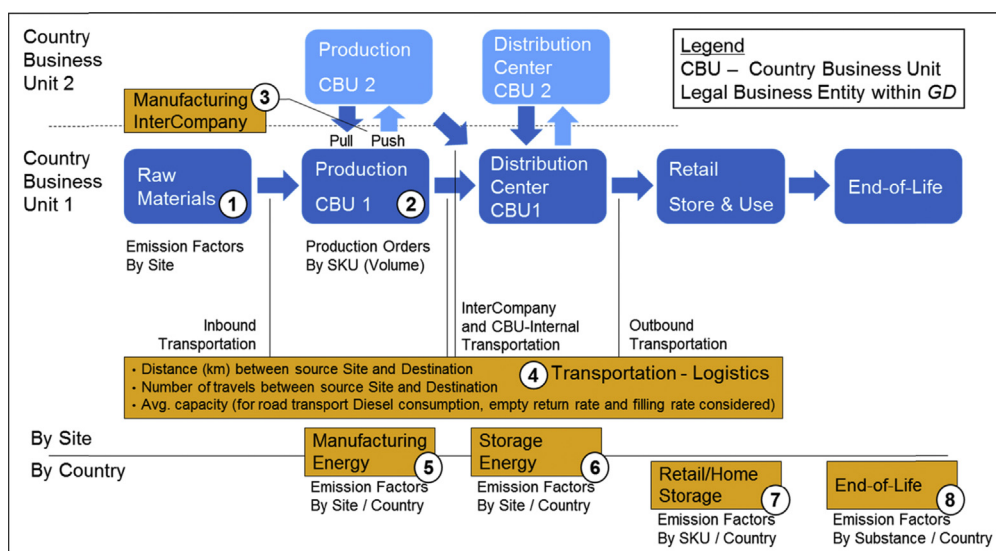


Fig. 2. Schematic presentation of the *GD* product system illuminates the applied carbon emission calculation rules.

Table 2Product life-cycle stages and the identified data sources at *GD*.

Life-cycle stage	Relevant data and business documents for emission calculation	Data sources
Materials	• EF per material by sites	• LCI databases • EF storage
Production	• Production orders by SKU by sites	• Production orders (<i>SAP</i> ERP)
Manufacturing Inter-Company	• Purchase orders by SKU by sites • EF of Manufacturing by country business unit	• Purchase orders (<i>SAP</i> ERP)
Logistics	• Decomposed by transportation mode • EF transportation mode • Transportation orders • Distances	• EF transportation mode (LCI databases) • Production orders (inbound logistics) (<i>SAP</i> ERP) • Outbound deliveries (<i>SAP</i> ERP) • Logistic rates (i.e. filling rates, empty-return rates) • Distance table (<i>SAP</i>)
Manufacturing Energy	• Decomposed by energy types • Energy consumption by site • EF energy types by country (or site)	• Consumption of energy collected from sites • EF energy types sourced from official LCI databases
Storage Energy	• Decomposed by energy types • Energy consumption by site • EF energy types by country (or by site)	• Energy consumption collected from sites • EF energy types from LCI databases
Retail/Home Storage	• EF by SKU by country • Volume shipped	• LCI databases • EF storage • Orders (<i>SAP</i> ERP)
End-of-life	• EF End-of-life by substance by country • Production orders by sites (regarding the composition)	• LCI databases • EF storage • Production orders (<i>SAP</i> ERP)

systems can enable an accurate account of the carbon footprint for large product portfolios, since they reflect respective changes in the business and are also supported by a uniform data model. The case example of *GD* supports this argument. With the help of real-time ERP systems it is possible to centrally store and maintain relevant data in few data sources and reflect changes in the supply chain consistently as they occur.

4.4. Scalability – coverage of large product portfolios

A key element of the ERP-based CF solution lies in the uniform data model with structured data (as described in Table 2), which applies to all products and life-cycle phases. Thus, changes or updates to the data (master data such as EF or changes to the composition or recipe of a product) can be consistently applied, thereby reducing manual error-prone effort and increasing accuracy. Integrated IT-platforms such as ERP are particularly suited to fulfil these requirements as they are designed to manage large sets of data. The potential for carbon information management associated with the high degree of re-use of data which is already captured in ERP systems seems to be underestimated. The case example for *GD* covers more than 35,000 SKUs. This is an order of magnitude higher than previous attempts at CF for large product portfolios, which do not make use of existing information. For instance, [Meinrenken et al. \(2012\)](#) investigate the capability of scaling and performing fast carbon footprinting for large product portfolios for a portfolio of around 1100 products in a consumer-product company.

Scalability was also achieved by decomposing the vast number of product components (more than 150,000 purchased raw materials) into a limited number of input substances (approximately 200). This approach reduces complexity and the associated effort for data maintenance significantly; yet provides additional detail and flexibility. In the case of *GD*, EF per substance is maintained country-specifically. Given the limited number of substances (200) and a maximum of some 100 countries across the globe, the data model covers a high degree of detail; while limiting the number of country-specific EFs to a maximum of 20,000 (200 substances times 100 countries). Thus, emissions associated with the purchase of components (raw materials and packaging), are determined by decomposing them into their substances. Therefore, the vast

number of components (~150,000) from different supplier sites (~250,000) can be modelled and handled by the system with little manual effort.

Table 3 summarises the scalability of the new system, while being able to cope with large data volumes. The solution aims to integrate 84 country business units that are operating around 700 sites in 40 countries. SKUs are composed of components which comprise a limited number of approximately 200 substances. The product portfolio includes 35,000 SKUs, which are produced out of roughly 150,000 components originating from approximately 250,000 supplier sites.

The case example provides evidence that the use of ERP enables scalability for carbon accounting across large product portfolios. Scalability is made possible with the help of ERP's uniform data model and by decomposing the number of product components into a limited number of input substances. The uniformity of its data model and the re-use of consistent data are the basis for scalability. Together they ensure that calculations can be performed consistently across a large set of suppliers, materials, sites and products.

4.5. Cost

GD intended to establish footprinting for almost its entire product portfolio at reasonable cost. Prior to the deployment of the product footprint solution, *GD* used to have large spreadsheets (MS Excel) to calculate the carbon product footprint for few of the SKUs. As a result of the introduction of the ERP system, the automated integration of data from the operative IT business systems reduced

Table 3

Selected entities of data model and the number of instances show the data volume.

Entity type	Number of instances
SKUs	~35,000
Brands	~600
Sub-Brands	~400
Components	~150,000
Supplier Sites	~250,000
Substances	~200

the effort in data-entry, accelerated the speed and reliability of relevant information. Since 80% of the data needed for the life-cycle analysis is automatically collected from the SAP ERP systems (see above), the effort of data collection and associated cost could be significantly reduced.

Thus, cost savings are based on the re-use of existing data stored in the ERP system and the related efficiency advantages in data collection. In addition, this enables replacing manual, error-prone calculation which in the past took more than a week for one product with an automated near real-time calculation of 35,000 distinct SKUs (Bardelline, 2012). Leveraging the capabilities of ERP systems can expand the size of the product portfolio covered by approximately a factor of 30 (from 1100 to 35,000 products). McKinnon (2010, p.50) cites Tesco for having “found a more cost-effective and standardised methodology” which reduced the average cost of carbon auditing by an order of magnitude to USD 4000 per product. He thus estimates that carbon labelling for the entire product range of a large retailer with around 75,000 line items would cost around USD 300 million. Under these assumptions the respective estimate for the portfolio of GD of around 35,000 would result in USD 145 million. Comparisons may be difficult as these figures do not clearly distinguish between one-time investments and recurring cost. However, even when taking the implementation cost into consideration it can be assumed GD has been able to cut the cost per SKU by at least one order of magnitude.

5. Conclusion and outlook

Public awareness of climate change has bestowed considerable relevance upon carbon information and CF in particular. Previous research argues that CF is associated with significant challenges in terms of effort and cost for the generation, collection, analysis, and communication of CF information. Therefore, several authors deem CF nonviable for large product portfolios, for example by arguing that “SKU-level carbon auditing of supply chains and the related carbon labelling of products will be fraught with difficulty and very costly” (McKinnon, 2010, p. 42). However, the literature review conducted unveiled a research gap, since to date little research has been conducted on the use of modern and widespread IT-based business systems, such as ERP, to overcome these challenges.

This paper fills this gap by an analysis conducted in a multinational company, where with the help of ERP systems and by leveraging existing information assets, a highly automated solution for monthly CF of a large product portfolio was realized. The study proceeds by shedding light on the requirements of a comprehensive carbon information management system and discusses the observed contribution of Enterprise Resource Planning (ERP) systems to carbon information management, particularly for large product portfolios.

The case contributes to the scientific discussion by demonstrating that ERP systems offer a viable approach to overcoming CF information challenges. As illustrated, the solution deployed provides the information transparency into carbon data necessary to achieve ambitious carbon reduction goals. The ability to manage information across a large product portfolio can generate helpful insights for decision making. A mix of secondary and primary data improves the accuracy of the results, although the quantification of these benefits will be subject to future research. Based on the case and its analysis, scientific value and implications for designing systems that enable large-portfolio CF are highlighted below.

First, due to the continuous tracking of business transactions, ERP systems can support the accurate and continuous accounting of carbon emissions. Second, on the basis of this IT-based capability the environmental impact can be allocated to product units. Third,

the use of ERP systems can lead to significant advantages for the simplification of data collection, as well as the accuracy and the consistency of calculation results. Fourth, real-time ERP systems can store and maintain relevant data centrally and are configurable to reflect changes in the supply chain reliably. Fifth, scalability is provided by ERP's uniform data platform and the extensive data re-use. As a result, it can be inferred from the case example that real-time ERP systems can enable an accurate account of the carbon footprint for large product portfolios.

The important management implications from this study are that companies can no longer avoid the topic of product CF simply on grounds of complexity and cost. The analysis of the challenges and how these were approached in the case study company can serve as an inspiration to other business organizations to initiate efforts in the direction of using wide-spread ERP and similar systems for CF. This, in turn, further legitimizes various stakeholders' demands for detailed and verifiable carbon information from companies. From a corporate perspective, besides carbon accounting, an approach like the one taken by GD facilitates the identification of CF hotspots within the product life cycle and the systematic reduction of carbon emissions. Moreover, with the increasing proliferation of ERP systems also within smaller and medium-size companies, the proposed cost-effective approach can also facilitate CF in small and medium-sized enterprises. Finally, this provides consumers with product-specific CF information to make better informed purchasing decisions.

The above findings need to be interpreted with three major limitations in mind. First, the case study company enables an initial, exploratory observation of leveraging ERP systems for CF. Follow-up investigations are therefore necessary to several questions that arise from it. In particular, the contingencies regarding the existing IT systems in a company may have an impact on the usability of information from such systems. Second, the extent to which carbon performance is affected by the company's activities determines the applicability of the approach presented in this paper. In other words, businesses with little tangible value creation (such as services) may not be able to take advantage of the findings in designing an IT-based CF system. Third, the case example presented covers a product portfolio with relatively limited complexity. Whereas the number of ingredients within dairy products is limited, complex products with multi-tier bill-of-materials and many variants (e.g. automobiles) offer additional challenges in terms of the number of components as well as the data volume to be handled.

Future research needs to investigate the potential role of IT in facilitating sustainability information management along supply chains. Despite the consensus that information exchange along the supply chain is critical, the role of IT for more sustainable supply chains has not been studied in detail. Moreover, the cost-benefit-ratio of CF would need to be explored for different industries. There is indication that this differs considerably according to the complexity of products and processes, materials used, logistics involved, and the variability of the supply chain. Last but not least, by focusing on the CF potentials that can be leveraged by using functionality and data available in ERP systems, this paper uncovers a further field for subsequent research: What would need to be done to the ERP data and how ERP data structures should be enhanced in order to generate the CFs for the company. Shedding light on this question is of large practical value to decision makers in particular.

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References

- Ardente, F., Cellura, M., 2012. Economic allocation in life cycle assessment. *J. Ind. Ecol.* 16 (3), 387–398.
- Ayres, R.U., Ayres, L.W., 2002. *A Handbook of Industrial Ecology*. Edward Elgar Publishing, New York.
- Bardelline, J., 2012. How Danone Is Pushing Carbon Further Down its Ingredients List. *GreenBiz.com*. March 29, 2012. Available online. <http://www.greenbiz.com/blog/2012/03/29/danone-reduces-carbon> (accessed on January 18, 2016).
- Bennett, M., Schaltegger, S., Zvezdov, D., 2013. Exploring Corporate Practices in Management Accounting for Sustainability. Institute for Chartered Accountants of England and Wales, London.
- Burritt, R., Schaltegger, S., Zvezdov, D., 2011. Carbon management accounting: explaining practice in leading German companies. *Aust. Account. Rev.* 21 (1), 80–98.
- Chenhall, R.H., 2003. Management control systems design within its organizational context: findings from contingency-based research and directions for the future. *Account. Organ. Soc.* 28 (2), 127–168.
- Chofreh, A.G., Goni, F.A., Shaharoun, A.M., Ismail, S., Klemes, J.J., 2014. Sustainable enterprise resource planning: imperatives and research directions. *J. Clean. Prod.* 71, 139–147.
- Craig, A., Sheffi, Y., Blanco, E., 2012. A Supply Chain View of Product Carbon Footprints: Results from the Banana Supply Chain. EDS Working Paper. Massachusetts Institute of Technology.
- Danone, 2012. Danone 2011 Sustainability Report. France, Paris.
- Danone, 2013. Danone 2012 Sustainability Report. France, Paris.
- Danone, 2016. Danone 2015 Registration Document, Annual Financial Report. France, Paris.
- De Benedetto, L., Klemes, J., 2009. The Environmental Performance Strategy Map: an integrated LCA approach to support the strategic decision-making process. *J. Clean. Prod.* 17, 900–906.
- De Haes, H.A.U., Heijungs, R., Suh, S., Huppes, G., 2004. Three strategies to overcome the limitations of life-cycle assessment. *J. Ind. Ecol.* 8 (3), 19–32.
- DeWalt, K.M., DeWalt, B.R., 2010. *Participant Observation: a Guide for Fieldworkers*. Rowman Altamira.
- Ernst & Young, 2011. Action amid Uncertainty: the Business Response to Climate Change. Ernst & Young, Geneva.
- Fakoya, M.B., van der Poll, H.M., 2013. Integrating ERP and MFCA systems for improved waste-reduction decisions in a brewery in South Africa. *J. Clean. Prod.* 40, 136–140.
- Finkbeiner, M., 2009. Carbon footprinting – opportunities and threats. *Int. J. Life Cycle Assess.* 14, 91–94.
- Funk, B., Möller, A., Niemeyer, P., 2009. Determination of environmental impact of products along the supply chain – an integration scenario. In: Wohlgemuth, et al. (Eds.), *Environmental Informatics and Industrial Environmental Protection*. Shaker Verlag, Aachen, pp. 367–374.
- Hack, S., Berg, C., 2014. The potential of IT for corporate sustainability. *Sustainability* 6, 4163–4180.
- Hochschorn, E., Finnveden, G., 2003. Evaluation of two simplified life cycle assessment methods. *Int. J. Life Cycle Assess.* 8 (3), 119–128.
- Holsapple, C.W., Sena, M.P., 2005. ERP plans and decision-support benefits. *Decis. Support Syst.* 38 (4), 575–590.
- Hörisch, J., 2013. Combating climate change through organisational innovation: an empirical analysis of internal emission trading schemes. *Corp. Gov.* 13 (5), 569–582.
- Jacob, M.E., van Sinderen, M.J., Steenwijk, M., Verkroost, P., 2013. Towards a reference architecture for fuel-based carbon management systems in the logistics industry. *Inf. Syst. Front.* 15 (5), 135–160.
- Jacobs, B.W., Singhal, V.R., Subramanian, R., 2010. An empirical investigation of environmental performance and the market value of the firm. *J. Op. Manag.* 28 (5), 430–441.
- Jensen, J.K., 2012. Product carbon footprint developments and gaps. *Int. J. Phys. Distrib. Logist. Manag.* 42 (4), 338–354.
- Jürgens, G., 2002. Materials flow management based on production data from ERP systems. In: Bennett, M.D., Bouma, J.J., Wolters, T.J. (Eds.), *Environmental Management Accounting: Informational and Institutional Developments*. Kluwer, Dordrecht, pp. 113–122.
- Kolk, A., Levy, D., Pinkse, J., 2008. Corporate responses in an emerging climate regime: the institutionalization and commensuration of carbon disclosure. *Eur. Account. Rev.* 17 (4), 719–745.
- Lee, K.H., 2011. Integrating carbon footprint into supply chain management: the case of Hyundai Motor Company (HMC) in the automobile industry. *J. Clean. Prod.* 19 (11), 1216–1223.
- McCall, G.J., Simmons, J.L., 1969. *Issues in Participant Observation: a Text and Reader*. Addison-Wesley Publishing Company, Boston, USA.
- McKinnon, A.C., 2010. Product-level carbon auditing of supply chains: environmental imperative or wasteful distraction? *Int. J. Phys. Distrib. Logist. Manag.* 40 (1/2), 42–60.
- Meinrenken, C.J., Kaufman, S.M., Ramesh, S., Lackner, K.S., 2012. Fast carbon footprinting for large product portfolios. *J. Ind. Ecol.* 16 (5), 669–679.
- Minx, J.C., Wiedmann, T., Wood, R., Peters, G.P., Lenzen, M., Owen, A., Ackerman, F., 2009. Input-output analysis and carbon footprinting: an overview of applications. *Econ. Syst. Res.* 21 (3), 187–216.
- Murphy, K.E., Simon, S.J., 2002. Intangible benefits valuation in ERP projects. *Inf. Syst. J.* 12 (4), 301–320.
- Palmeiro, L., Catteloin, R., 2011. How to calculate, analyse and manage the Carbon Footprint of 35,000 products. In: Presentation at the 6th PCF World Summit, Berlin, 26–27 October 2011.
- Pandey, D., Agrawal, M., Pandey, J.S., 2010. Carbon footprint: current methods of estimation. *Environ. Monit. Assess.* 178, 135–160.
- Reap, J., Roman, F., Duncan, S., Bras, B., 2008. A survey of unresolved problems in life cycle assessment. *Int. J. Life Cycle Assess.* 13 (5), 374–388.
- Sarkis, J., Koo, C., Watson, R.T., 2013. Green information systems & technologies – this generation and beyond: introduction to the special issue. *Inf. Syst. Front.* 15 (5), 695–704.
- Scapens, R.W., Jazayeri, M., 2003. ERP systems and management accounting change: opportunities or impacts? A research note. *Eur. Account. Rev.* 12 (1), 201–233.
- Schaltegger, S., 1997. Economics of life cycle assessment: inefficiency of the present approach. *Bus. Strateg. Environ.* 6, 1–8.
- Schaltegger, S., Burritt, R., 2000. *Contemporary Environmental Accounting. Issues, Concepts and Practice*. Greenleaf Publishing, Sheffield, UK.
- Schaltegger, S., Csutora, M., 2012. Carbon management accounting: challenges and approaches. *J. Clean. Prod.* 36, 1–16.
- Schmidt, M., 2009. Carbon accounting and carbon footprint – more than just diced results? *Int. J. Clim. Change Strateg. Manag.* 1 (1), 19–30.
- Stechemesser, K., Günther, E., 2012. Carbon accounting: a systematic literature review. *J. Clean. Prod.* 36, 17–38.
- Symon, G.E., Cassell, C.E., 1998. *Qualitative Methods and Analysis in Organizational Research: a Practical Guide*. Sage Publications Ltd.
- Tukker, A., Jansen, B., 2006. Environmental impacts of products: a detailed review of studies. *J. Ind. Ecol.* 10 (3), 159–182.
- Weber, C., 2011. Uncertainty and Variability in Carbon Footprinting for Electronics Case Study of an IBM Rack-mount Server. Carnegie Mellon University.
- Wiedmann, T., Lenzen, M., Barrett, J.R., 2009. Companies on the scale: comparing and benchmarking the sustainability performance of businesses. *J. Ind. Ecol.* 13 (3), 361–383.
- Zapico, J.L., Brandt, N., Turpeinen, M., 2010. Environmental metrics. *J. Ind. Ecol.* 14 (5), 703–706.