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Article

Application of Environmental Input-Output Analysis for Corporate and Product Environmental Footprints—Learnings from Three Cases

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Abstract: An increasing number of companies are expanding their environmental impact reduction targets and strategies to include their supply chains or whole product life cycles. In this paper, we demonstrate and evaluate an approach, where we used a hybrid Environmental Input-Output (EIO) database as a basis for corporate and product environmental footprint accounts, including the entire supply chain. We present three cases, where this approach was applied. Case study 1 describes the creation of total corporate carbon footprint accounts for three Danish regional healthcare organisations. In case study 2, the approach was used as basis for an Environmental Profit and Loss account for the healthcare company, Novo Nordisk A/S. Case study 3 used the approach for life cycle assessment of a tanker ship. We conclude that EIO-based analyses offer a holistic view of environmental performance, provide a foundation for decision-making within reasonable time and cost, and for companies with a large upstream environmental footprint, the analysis supports advancing their sustainability agenda to include supply chain impacts. However, there are implications when going from screening to implementing the results, including how to measure and monitor the effect of the different actions. Thus, future research should include more detailed models to support decision-making.

Keywords: environmental footprint; carbon footprint; life cycle assessment; hybrid environmental input-output database; sustainable business development; green supply chain; environmental profit and loss; natural capital accounting

1. Introduction

Companies with ambitious sustainability agendas are starting to expand their efforts from reducing directly controlled environmental impacts within their own operation to also including supply chain embedded impacts [1]. These companies recognize that the indirect impacts from consumption of raw materials, machinery, equipment and other supporting products and services can have a significant share of the total environmental impact related to the company's activities. Looking at greenhouse gases as a single indicator, carbon footprint studies show that, depending on the sector, embedded emissions upstream in the value chain can account for up to and over 90% [2,3]. This is especially the case for service-oriented companies, where environmental loads, such as air emissions, are not produced at the actual site of activity but are indirect impacts [4]. The growing field of green supply chain management reports that many companies experience a pressing need to know how other stakeholders in the value chain influence the environmental performance of the products or services that the company delivers to its customers [5,6]. This can be supported by another growing field: environmental (especially carbon) footprinting (see, e.g., Lenzen [7] or Wiedmann [8]), putting quantitative measures into play—on both corporate and product levels. An environmental footprint can be defined as "a measure of natural resource usage and environmental impacts for which a company or product is responsible within the life-cycle of its entire operations" (adjusted from Ewing *et al.* [9]). In carbon footprinting, only greenhouse gas emissions are captured.

Life Cycle Assessments (LCA) that are based on Environmental Input-Output (EIO) analyses are reported to be a promising approach to achieve environmental quantifications, including all supply chain impacts [3,8,10–12]. An EIO analysis is a "top-down" approach, capable of capturing impacts from the entire supply chain and is useable as a screening tool to inform estimation of the anticipated life cycle emissions [2]. However, the approach is also criticised, mainly for being too aggregated, thus causing the need to hybridize with "bottom-up" data collection, where the generic EIO model is evaluated as being insufficient [2,13–15].

A number of studies on applied EIO analyses can be found in the literature [2,14,16,17]. In most of these studies, focus has been on demonstrating EIO analysis as a tool to overcome the hurdles of time-consuming data collection and incompleteness of traditional LCA methods.

In this paper, we take the research a step further. Based on applied EIO analyses, we evaluate how the approach can be used by companies in their strategic sustainability work, including supply chain management and procurement activities. We attempt to investigate how companies might apply EIO analysis for corporate and product environmental footprints, aiming to answer the following two research questions:

RQ1: What are the Strengths and Weaknesses of the EIO Approach?
RQ2: How Does Application of the EIO Approach Influence the Companies' Environmental Agenda?

To answer these questions, we have conducted a literature review on EIO analysis and used three case studies to demonstrate and evaluate the approach, utilising a hybrid EIO database as the basis for the calculations. The cases are very diverse in nature but are all characterised as complex systems that depend on many inputs of products and services. The first two cases analysed environmental footprints on corporate levels and the third case was a life cycle assessment on the product level (albeit as large and complex a product as a ship). In total, five companies were involved in the research and they all provided feedback on the analyses through meetings, workshops and interviews in order to conclude on the applicability of the approach. We discuss the findings with support of relevant external literature. The three cases are introduced in the following.

1.1. Case 1: Corporate Carbon Footprint Account of Three Danish Regional Healthcare Organisations

Denmark is administratively divided into five geographical Regions, which share the responsibility for all treatment provided by the Danish Healthcare System [18], with the primary function being provision of hospital services. In addition to their core business of healthcare provision, all five organisations are focused on reducing greenhouse gas emissions from their activities, through climate strategies, action plans and various initiatives. The total carbon footprint accounts presented in this article were commissioned by three of the five Danish Regions, independently of each other. For full reports (in Danish) see [19–22].

The carbon footprint accounts were commissioned with the purpose of expanding the scope of greenhouse gas reporting from use of energy to also include embedded emissions in the delivering products and services, in order to show an ambitious climate change agenda and prioritise carbon reducing initiatives. The purpose was also to add knowledge to the ongoing process of green procurement, including environmental demands in tenders and purchases. Collaboration with the three Regions on creating and updating carbon footprint accounts has been ongoing for more than five years.

1.2. Case 2: EIO Analysis Used for Environmental Profit and Loss Accounting of Healthcare Company Novo Nordisk A/S

An Environmental Profit and Loss Account (EP&L) is an effort to account, in financial terms, for the resources upon which a company, and its entire value chain, rely, plus the environmental impacts generated. EIO analyses can be used to quantify the environmental impacts, which are then monetised. In 2012, sports apparel company PUMA was the first global corporation to publish an EP&L [23]. Inspired by this case, in 2013, The Danish Environmental Agency initiated an EP&L of the Danish healthcare company Novo Nordisk A/S as a new case example [24,25]. Novo Nordisk is a global healthcare company, which core business is diabetes care. The company is responsible for the production of more than 50% of the world's insulin. The company also has leading positions within haemophilia care, growth hormone therapy and hormone replacement therapy. Environmental and social responsibility is included in the company's articles of association, and the business philosophy is one of balancing financial, social and environmental considerations in what is called the Triple Bottom Line [26].

For Novo Nordisk, conducting an EP&L was a natural step to enhance knowledge on supply chain impacts and explore the opportunities to reduce the company's environmental impact in the upstream part of the value chain.

1.3. Case 3: Life Cycle Assessment of a Tanker Ship Operated by Shipping Company TORM A/S

TORM A/S operates within the area of clean petroleum product shipping. As in many other shipping companies, TORM's environmental concern has to do with adhering to regulations set by the International Maritime Organisation (IMO). Furthermore, after experiencing a period of rising bunker fuel prices TORM was incentivised to reduce their ships' fuel consumption. The economic recession, which had its onset in 2008–2009, forced many shipping operators to evaluate a series of operational and technical optimisation solutions, in an effort to cover costs and create a sustainable shipping environment [27]. In this case study 3, the EIO approach was tested as a method to combine Life Cycle Costing (LCC) and LCA in a common framework, using financial data as the main basis of both. This article presents the results of the assessment of one of TORM's tanker ships. The analysis and elaborated methodology can be found in Kjær *et al.* [28].

2. EIO Analysis

The first Input-Output (IO) models were developed for economic calculations, by U.S. economist Leontief, in 1936 [29]. He constructed a linear model of the U.S. economy relating the production inputs of goods and services in an economy to the production outputs of other sectors [2,10]. Today, almost all countries regularly compile IO tables as part of their national accounts. An IO table accounts for all product flows between sectors in the economy. The IO table can be extended with direct emission and resource data for each sector, making it possible to calculate the life cycle impacts from cradle to gate per monetary unit spent for each product output. Utilising the environmentally extended IO model to gain environmental insights is termed an Environmental Input-Output (EIO) analysis. The EIO analysis is consistent with how impacts are calculated in a traditional life cycle assessment. The only differences are that the transactions between the activities are measured in monetary units instead of physical units, such as kilograms or kWh, and that the data collection in EIO is top-down, whereas a traditional or process-based LCA typically uses a bottom-up approach. In a process-based LCA, data are collected for all the processes that have been identified as important to include within the chosen system boundary. This approach has the disadvantage of truncation errors, since it will always be a subjective evaluation of which processes to include. Analysts are often forced to simply ignore many facets of life cycle impacts due to lack of data availability and time restrictions [30], and, especially, uses of services are typically ignored [4]. Studies show that process-based LCAs can underestimate emissions by as much as 50% [4,14,31]. Furthermore, doing a comprehensive process-based LCA of all the products and services a company are requiring, in both direct operations (in the production chain) and indirect operation (administration, R&D, marketing, *etc.*), would quickly become a prohibitive task. EIO analyses offers a top-down approach without any cut-offs and with the possibility of easy inclusion of uses that are only measured in monetary terms, such as services [4]. This makes the approach suitable for hotspot analysis and boundary decisions [2,10,32].

Despite its many qualities, there are also a number of drawbacks with the EIO approach, as described in the literature. The main weakness mentioned is sector aggregation, meaning that sectors may be too heterogeneous to correctly reflect a particular process or product [11,17,32–34]. Other potential weaknesses, depending on the EIO model, include: data age [17,33], use of monetary units (price fluctuations and inhomogeneity) [33], insufficient handling of waste treatment [14,33], a limited number of environmental indicators [14], potential exclusion of capital investments [14], and no or limited accounting for regional differences and international trade [11,35].

Taking a hybrid approach, where the detail level of a process-based LCA is combined with the completeness of EIO models, is suggested by many as the way forward to mitigate uncertainty in compiling life cycle inventories [2,13,14,32,36–38]. The term hybrid can refer to two things: a *hybrid database* and a *hybrid analysis*. In a hybrid database, IO analysis and mass flow analysis are fully integrated, creating a mixed unit database with biophysical units for all mass and energy products and monetary units for all service products and capital goods. The advantage of a hybrid database is the possibility of using physical data instead of monetary data when available, since physical data is often less uncertain and also more stable over time than monetary data [39].

In a hybrid analysis, the "top down" EIO data is combined with "bottom up" process-based data in either a tiered or embedded (also called integrated) approach [34,39]. In the tiered approach, EIO data is used to supplement the process-based data by, e.g., adding service and capital good expenses to the inventory. The embedded approach fully integrates the process-based data into the EIO model, resulting in the same completeness as the original EIO table but at a higher level of detail.

The approach used in the case studies presented in this article was based on a hybrid unit EIO database (described in Section 3) and includes the use of hybrid analysis for selected processes. Both tiered and embedded approaches were applied, depending on wishes of the study commissioners. For the tiered approach, it should be noted that this approach inevitable entailed truncation errors when comparing to the fully EIO integrated parts of the analysis.

This article contributes to the ongoing research on EIO analyses by demonstrating the use of a hybrid EIO approach for comprehensive corporate and product environmental footprints and discusses its usability for companies in advancing their environmental agenda.

3. Applied Method

In applying the EIO approach, we utilised a specific database, modelling approach and data collection strategy, as described in the following.

3.1. Hybrid Database FORWAST

The analyses done in the three case studies were based on an EIO database called FORWAST. FORWAST was developed as part of the Research Project of the 6th European Union Framework Programme [40]. Later improvements of the original FORWAST model are listed in Table 1.

Table 1. Modifications of the original FORWAST model.

Modification	References for Documentation of the Improvements
Danish agriculture and food industry was further detailed.	Hermansen *et al.* (2010) [41]
More emissions were added: nitrate, phosphate.	Hermansen *et al.* (2010) [41]
More emissions were added: particles.	Kjær *et al.* (2011) [22]
Import to Denmark was divided into import from EU27 and from rest of the world (RoW).	Kjær *et al.* (2011) [22]
Land occupation was added as a resource input in the database.	Schmidt and Muñoz (2014) [42]
A model for indirect land use changes was embedded in the model.	Schmidt and Muñoz (2014) [42]

FORWAST is a so-called hybrid database as it is based on economic data from the national accounts, as well as process-specific data from life cycle inventories (used for sector disaggregation). The transactions in the model are in different units: dry matter for physical products, energy units for electricity/heat/steam, and monetary units for other flows in the economy such as services. The database distinguishes between different waste fractions and their treatment: recycling, incineration and landfilling. Waste streams are determined by detailed mass balances. The model is based on data from 2003.

The original FORWAST database included 132 products/sectors. In refining the model, relevant sectors were disaggregated using statistical data to provide a better match to the specific uses in each of the case studies. These sectors included “Chemicals” (to separate pharmaceuticals from other chemical products), “Machinery and equipment”, “Health and social work”, “Land transport and transport via pipelines”, and “Hotels and restaurants”.

3.2. Hybrid Modelling

For relevant processes we hybridised with process-based data. An example was the modelling of ambulance transportation used by the Regions (case study 1). The process “Taxi operation”, which was a disaggregation of the sector “Land transport and transport via pipelines”, was modified to represent ambulance transportation by using the fuel efficiency of the ambulances in the actual fleet. Another example from case study 2 (Novo Nordisk) was the modelling of glucose used for insulin production. The EIO sector most appropriate for glucose was identified and assessed. Detailed glucose production data were merged into the EIO model to make a new and more precise profile for glucose production. A full explanation of this particular hybridisation can be found in Høst-Madsen *et al.* [24].

3.3. Data Collection and Analysis

Since the used database was a hybrid EIO table using both monetary and physical units, upstream emissions were calculated either per monetary unit (e.g., Danish krone (DKK)) spent on products or services, or from physical consumption such as energy use, fuel use, and materials use in physical units (kWh or kg).

In order to ensure full completeness in scope and full economic balance, complete annual expenditure (referred to in this research as “spend”) accounts for each entity (e.g., hospital, production site, ship) were provided by the company as the starting point. For the ship, data for five years of operation were gathered.

Each spend was assessed and matched against the best representing EIO sector. For very broad and/or large spend categories an extra assessment was made, e.g., by gathering invoices from suppliers, making it possible to disaggregate the spend category to better match the categories in the EIO model.

As the FORWAST database required input in the currency EURO2003, all spend were turned into 2003 prices using inflation indexes and transferred into EUROs by the currency rate in 2003.

The process of gathering and analysing data is presented in Figure 1. First, all spend were summed up for the categories chosen for the final results. Then, for fuel end energy consumption the financial input data were replaced with data on actual consumption in physical units for which hybrid processes were created for each type of energy sources. The same was done for selected focus areas within, e.g., transportation and purchased materials and products, where the companies were able to provide data in physical units (kg) to allow more precise calculations. For materials and products where data on uses in physical units were not retrieved, dry weight commodity prices for the specific sector as provided by FORWAST were applied. As an example, for a ship's use of engine stores, which mostly covered hand tools, we used the average price that the sector "Transport by ship" paid for "Fabricated metal products".

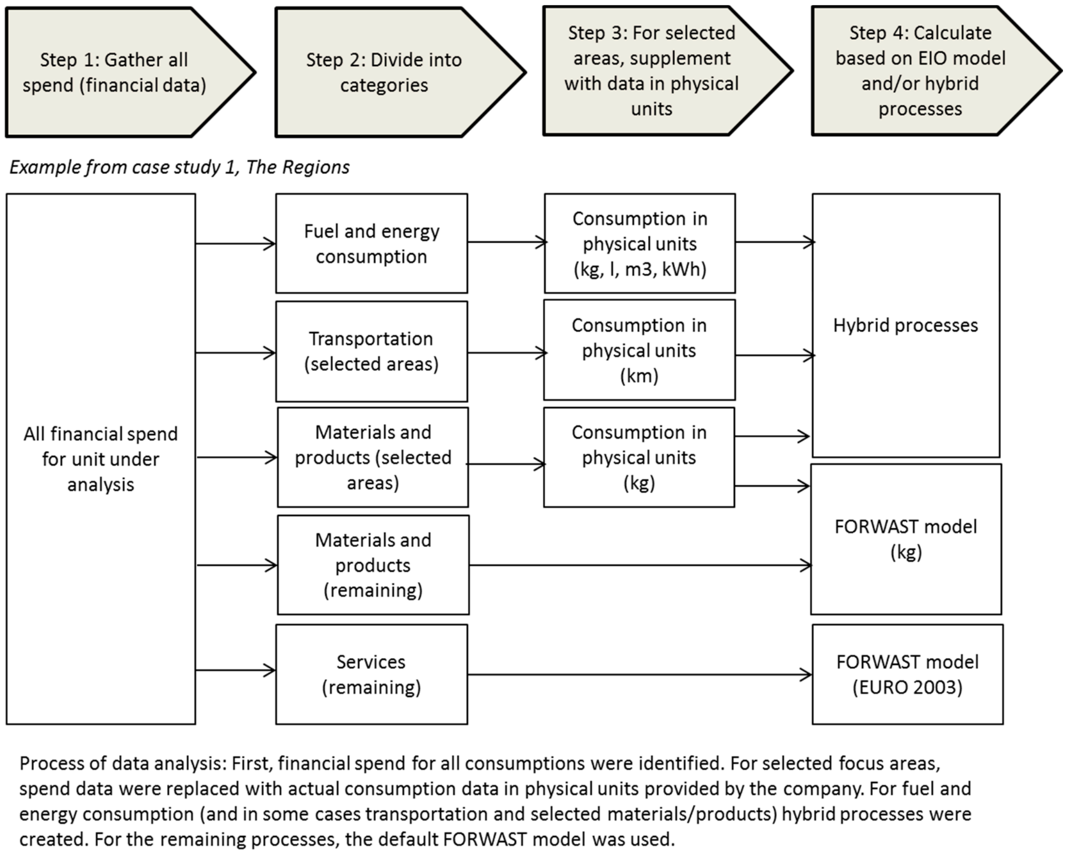

Figure 1. Process of data analysis.

Calculations were performed in SimaPro—software developed to assist LCA and carbon footprinting. SimaPro facilitated analyses with both the EIO tables and other large LCA databases, such as Ecoinvent, allowing for hybridisation.

For case study 1 (Regions), the Greenhouse Gas Protocol (GHG protocol) was used as framework for presenting the results [43]. The GHG protocol is limited in the environmental scope, as it only deals with greenhouse gas emissions. However, it provided a framework, dividing emissions into scopes, which were also used by the Carbon Disclosure Project in their reporting framework [44]. Scope 1 covers emissions from sources under the company's direct control, scope 2 covers indirect emissions from purchased energy (e.g., electricity) and scope 3 covers all other indirect emissions upstream and downstream in the company's value chain, including purchased products and services. The International Panel of Climate Change (IPCC) global warming potentials in a 100-year time horizon (GWP100) were applied to convert single emissions, such as CO_2, CO, CH_4 and N_2O, into a single unit: greenhouse gases measured in CO_2 equivalents (CO_2e).

For case study 2 (Novo Nordisk), the results were distributed between own operation and supply chain impacts, which were further divided into tier 1, 2 and 3 suppliers. The following environmental indicators were obtained: Greenhouse gas emissions: CO_2e. Air pollution: SO_2, NMVOC, NH_3, particles (<10 µm) and NO_x. Water use: Water quantities (m^3). The method for monetary valuation is outside the scope of this study and can be found in the EP&L methodology report [24].

For case study 3 (a TORM tanker ship), CO_2e, SO_2, particles,and NO_x were included in the inventory, however the analysis was only used to show results for the carbon footprint of the ship.

For capital investments, different scopes were applied for the different cases. For the Regions, emissions related to capital spend were presented in a separate account to be able to monitor the operational development independently of capital investment. Capital spend were merely included to highlight that capital investments also have a carbon footprint. For Novo Nordisk, capital spend were not included. For the tanker ship, emissions from capital investments (ship building and five year dry dock repairs) were distributed over the operational lifespan of the ship.

3.4. Follow-up and Evaluation

Different activities where initiated with the companies to get their feedback on the applicability of the approach and contributions to their environmental agenda, especially in order to answer RQ2.

For the Regions, the carbon footprint accounts ran in parallel with consultancy support on climate mitigation strategies, involving regular meetings and workshops with key stakeholders. During these meetings, it was discussed how the carbon footprint accounts would feed into the strategic work and how the effect of initiatives could be monitored in future updates of the accounts. These activities provided valuable feedback on the methodology's usefulness and limitations, as well as knowledge on opportunities and barriers for influencing the supply chain.

For Novo Nordisk, the case study was followed up by a presentation to the management, including a discussion on the results and implications of the study. Furthermore, the authors of this paper conducted a semi-structured interview with the Programme Director, Corporate Sustainability, in order to get more detailed feedback on the applicability of the analysis. Finally, we consulted an expert review of the PUMA EP&L [45] as a means to validate the applicability of the approach. In TORM, results were presented and discussed at meetings with a vice president in the technical division. Since the primary environmental strategy of the company was related to reducing fuel consumption, the discussions focussed on which initiatives could contribute to this, including technical retrofits and more efficient operation. Thus, in contrast to the first two cases, the study did not reveal any reasons to change this agenda, and, therefore, no further discussions on influencing the indirect impacts in the supply chain were initiated.

Since, in all cases, connecting the environmental footprints to green supply chain initiatives was still preliminary, we have supplemented the discussion in this paper with selected core literature on green supply chain management.

4. Case Study Results

This section presents the outcome of the three case studies showing examples of calculated results and findings in relation to the two research questions.

4.1. Case Study 1: Total Corporate Carbon Footprint Account of Three Danish Regional Healthcare Organisations

The carbon footprint accounts for the Regions were made as yearly accounts. Results were divided into categories and provided for each organisational sector (primarily hospitals) under each Region's administration. Results showed that 15%–21% of greenhouse gas emissions were related to the use of energy (scope 1 and 2 in the GHG Protocol), while the remaining 79%–85% were embedded upstream the value chain in purchased products and services (scope 3 in the GHG Protocol). Figure 2 shows the distribution between scope 1 + 2 and 3 for the year 2011 for all three Regions.

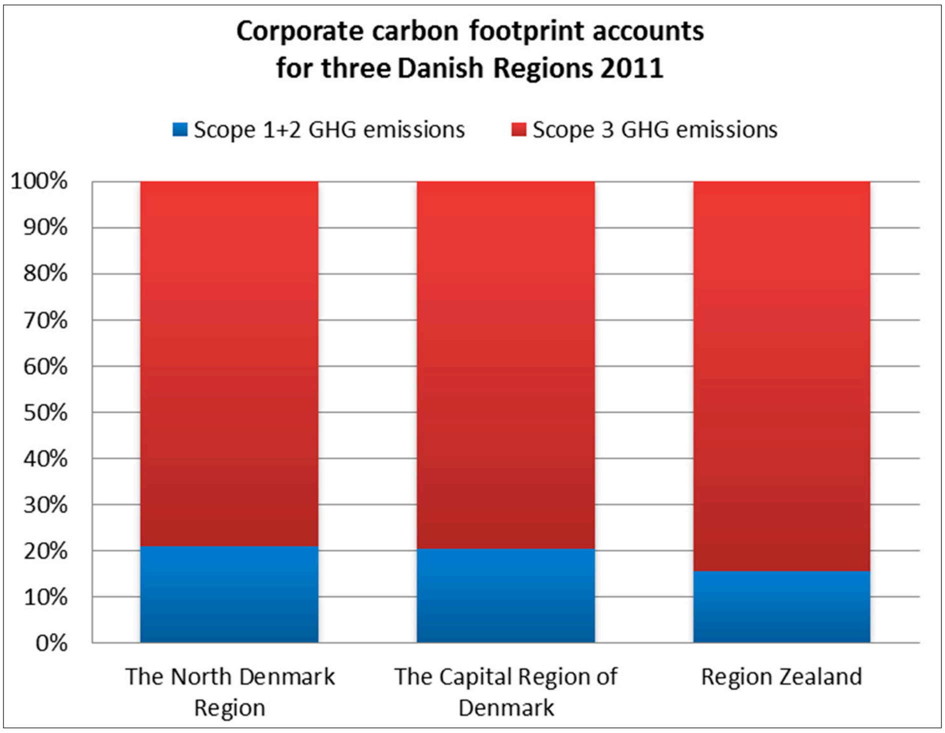

Figure 2. Corporate carbon footprint accounts for three Danish Regions 2011, division between scopes according to the GHG protocol.

In addition to providing the absolute number in CO_2 equivalents (CO_2e), a number of key performance indicators (KPIs) were established, in order to monitor the development over the years. KPIs included: CO_2e/employee, CO_2e/square meter, CO_2e/hospitalised patient days (also called "bed days"), CO_2e/ambulant visits and CO_2e/DKK spend (DKK is the Danish currency). Each Region commissioned the studies independently and, thus, had different KPIs and year ranges. As an example, Table 2 shows the development of three KPIs for The North Denmark Region (all organisational sectors included) for the years 2007 to 2012.

Table 2. Key performance indicators (KPIs) for The North Denmark Region 2007–2012.

KPI	2007	2008	2009	2010	2011	2012
t CO_2e/employee	17.4	18.2	17.1	16.5	14.7	14.6
Kg CO_2e/m^2	323.6	347.0	351.9	344.1	302.5	302.3
Kg CO_2e/DKK	67.8	63.3	60.9	61.1	56.8	53.2

The KPI CO_2e/DKK helped to show the carbon efficiency in relation to financial spend. Since the total carbon footprint would increase or decrease with the annual budget, monitoring CO_2e/DKK took that variable out of the equation. In Figure 3 we show the carbon footprint in relation to financial spend for the Capital Region of Denmark in 2011. The figure shows that "patient articles", including medicine, was the largest spend category, accounting for 38% of the total spend. However, "Patient articles" only accounted for 19% of the carbon footprint. This has to do with the fact that medicine is generally relative expensive, and a lot of the money spent on medicine goes to service-related activities, such as research and development. An example of the opposite was the category "food" that only accounted for 2% of the total spent, while it accounted for over 10% of the carbon footprint.

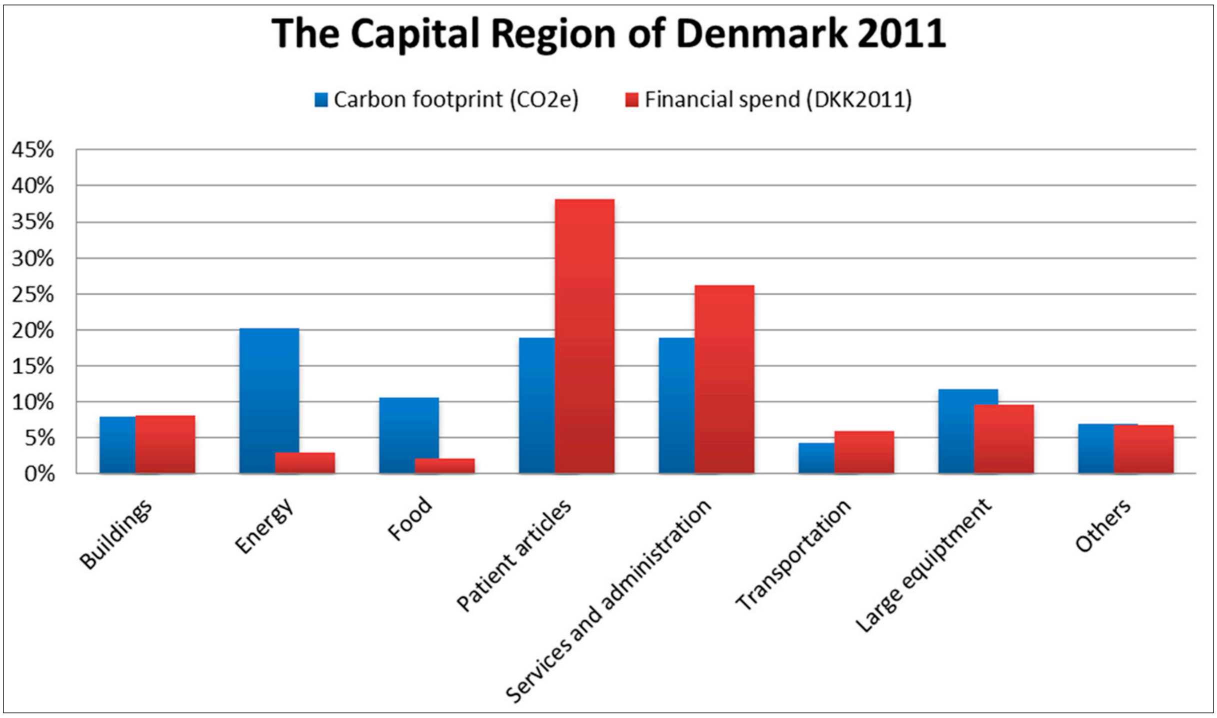

Figure 3. Corporate carbon footprint account for the Capital Region of Denmark 2011. Carbon footprint and financial spend for each category.

The carbon footprint accounts firstly had the purpose of showing company responsibility and secondly to serve as an eye-opener to the indirect emissions embedded in the supply chain (scope 3). In relation to RQ1, the strength of the EIO approach was that it made a first screening of the total impact feasible, since the analyses were based on annual financial data, which was readily available within the organisations.

The main limitation was seen as the ability to move from screenings based on average data to more detailed accounts based on data from the actual supply chain in order to initiate and monitor improvements.

For all three Regions the following focus areas were identified as hotspots and recommended to detail and monitor: "energy", "food", "transportation" and selected products within "patient articles" and "large equipment". For food, it was recommended to investigate if the amount of meat (especially red meat) could be reduced and to reduce the amount of food waste. Monitoring of this area would require collecting data on actual purchased amounts in physical units (kg) divided into product categories for all participating kitchens and canteens.

Transportation was divided into patient transport and personnel transport, with patient transport constituting the largest part. Before being able to monitor the development within patient transport, it would be necessary to implement a system where the transport provider would report information, such as: distance travelled (km), occupancy rate (for translation into person*km), and fuel consumption (km/L), since these would be the main variables for reducing the impact from the transport service. As a supplement to established KPIs related to quality, safety and cost, The North Denmark Region chose to measure these environmental related KPIs for planned patient transport and implement them in future updates of the carbon footprint account.

Based on the analysis, it was also recommended to investigate reduction potentials within purchased equipment (electrical and non-electrical) and patient articles (medical articles, textiles, hygiene products, *etc.*). A first step would be to acquire more detailed information from the suppliers in order to ensure transparency. Relevant data could be: emission data, amount of materials used and production method including geography, power use and power sources. Based on this, the Regions would have the necessary information to initiate a dialogue with suppliers on how they could improve the environmental performance of the products. Thus, in relation to RQ2, the carbon footprint accounts contributed to an increased focus on purchase and consumption as important focus areas in the Region's climate strategies and action plans. However, for all three Regions, we did not experience that reducing upstream emissions was a highly prioritised political goal from the beginning, and, as in any political organisation, changes take time. Nevertheless, within each of the three Regions that commissioned the analyses, passionate employees were driving the agenda forward. One concrete result of the carbon footprint accounts was the North Denmark Region, which was the first public company disclosing all upstream scope 3 emissions to the Carbon Disclosure Project (CDP).

During the work on climate mitigation strategies for the companies, it became clear that focus areas were not only decided based on their relative size in CO_2e. Other selection parameters such as supplier relationship and supplier readiness were also important. As an example, it would not be feasible to ask a transportation provider to use electric vehicles for patient transport, since no transport company would be able to provide such a fleet. Another selection parameter was the ability to monitor the improvement. If it was not possible to gather sufficient data to document improvements, the project would not have the required political backup. Other influencing parameters were current political focus (what was "hot topics" on the political agenda) and previous initiatives (where they already had commitments). For one Region, Region Zealand, five decisive parameters were formulated to prioritise climate change actions:

(1) CO_2—effect (reduction potential)
(2) Implementation costs

(3) Organisational process
(4) Branding effect
(5) Data availability (to monitor improvements on a detailed level)

Based on these parameters, 11 initiatives were selected for further exploration. The following areas were aiming at reducing scope 3 emissions: reduction of food waste, food waste as biogas, travel, and green procurement. Green procurement had two main focuses; (1) focus on requirements towards energy consuming products and (2) focus on requirements towards non-energy consuming products. Again, getting from a carbon footprint screening to a robust monitoring system, where improvements can be traced and documented, was seen as a challenge needed to be overcome for the EIO approach to be fully implemented with political goals and actions.

4.2. Case Study 2: Novo Nordisk Environmental Profit and Loss Account

Figure 4 illustrates the total monetised environmental impacts of Novo Nordisk in 2011 for the three environmental KPIs: water use, greenhouse gasses and air pollution. The total monetised environmental impact amounted to 223 million Euros. The main monetised environmental impact (total 77%) related to greenhouse gasses, which supported the company's own assessment of environmental impacts. As shown on Figure 4, impacts were divided according to two spend types: Direct spend and Indirect spend. Direct spend related to the production of Novo Nordisk pharmaceutical products and devices, and included operational energy usage, water usage and the raw materials purchased from the supply chain. Indirect spend covered all products and services, which were not part of the final consumer product. This included, *i.e.*, IT equipment, furniture and machinery.

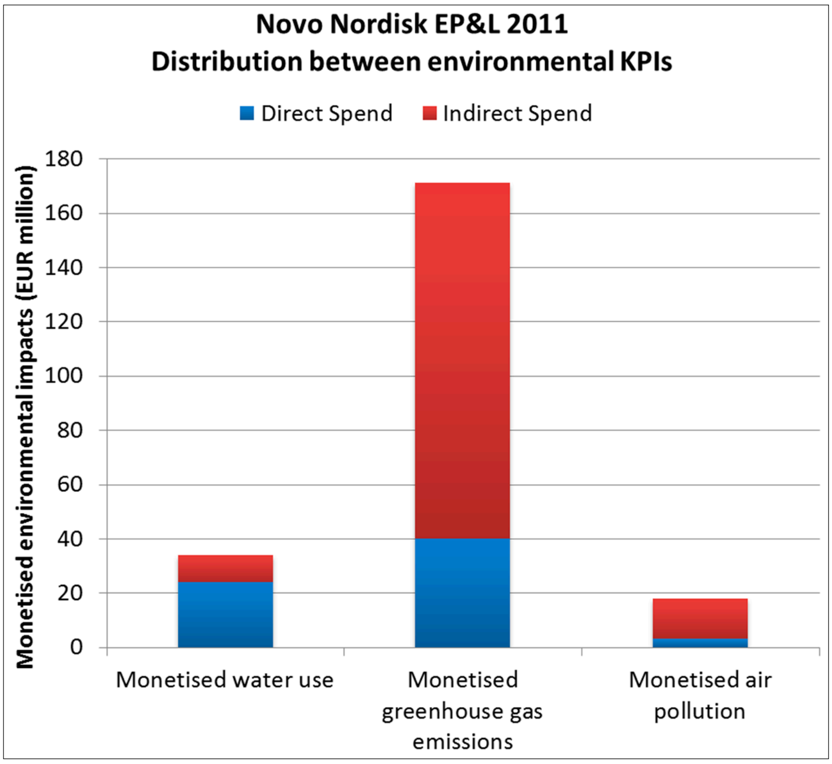

Figure 4. Total monetised environmental impact distributed between the three environmental KPIs: water use, greenhouse gasses and air pollution.

Results were furthermore distributed between own operation and tier 1, 2 and 3 suppliers to illustrate where in the value chain the main impacts occurred. Tier 1 covered finished products and services, tier 2 processed materials and tier 3 raw materials. As shown in Figure 5, the main environmental impacts occurred in tier 1 and tier 3 (total 75%). Novo Nordisk's own operations constituted only 13% of the total environmental impact.

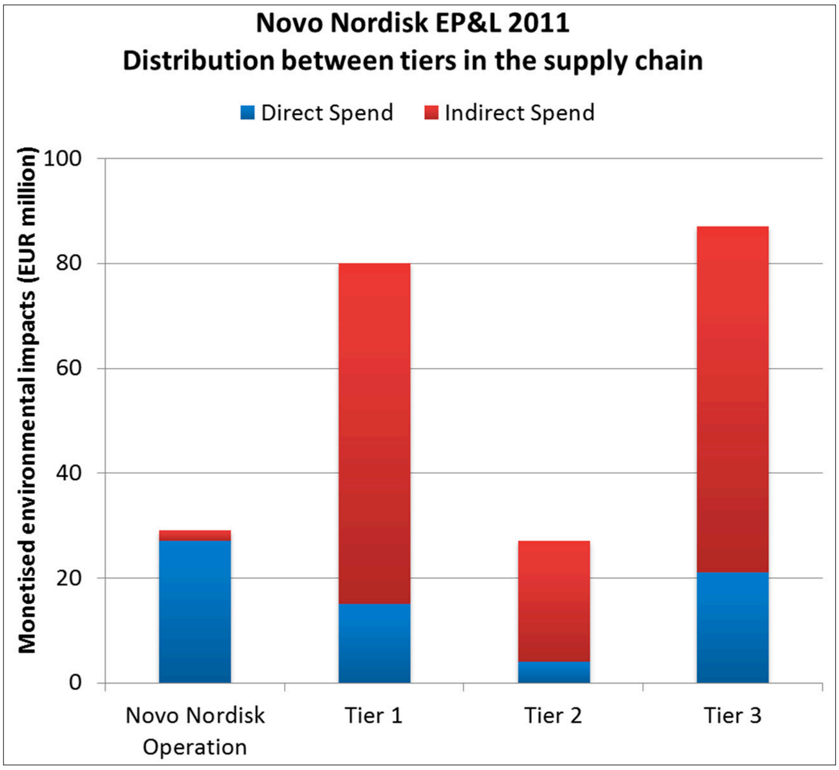

Figure 5. Monetised environmental impacts distributed between tiers, shown for Direct and Indirect spend.

The environmental impacts relating to Indirect spend amounted to 70% of the total. Although the majority of impacts lay within Indirect spend, Direct spend was where Novo Nordisk had a greater sphere of influence, since the majority of their own operation was represented here, as shown in Figure 5. In other words, the majority of Novo Nordisk's environmental impacts lay outside its direct control and would therefore be more challenging to reduce.

In relation to RQ1, using the EIO approach as the basis for the EP&L was discussed with Novo Nordisk, and the uncertainty of the results was taken up as a discussion point. Novo Nordisk has worked for many years with conducting LCAs on their products. In these analyses, accuracy in the results was considered very important, as it was used for reporting to customers. However, in the case of EP&L, the EIO approach was considered appropriate. The uncertainty involved in both environmental impact calculations and in the subsequent monetary valuation were not considered crucial, since the analysis was primarily used as a communication tool to put new subjects on the agenda—the actual numbers were not to be used for reporting or monitoring. In this way, the EP&L assisted in validating current reduction strategies and identify whether there were areas which could be included in future strategies. However, for the methodology to be fully implemented in the strategic work in Novo Nordisk, it would have to develop from a screening tool into a strategic tool that could support decision-making. This process would involve moving from accounting to creating budgets and enable scenario development. Having a budget-EP&L would enable comparison of investments before they were made. It would help quantify different strategic paths, and help the decision makers in an organisation make more sustainable decisions.

Similar to the carbon footprint accounts for the three Regions described above, the primary goal of the first EP&L was to show that Novo Nordisk took their environmental responsibility seriously and to show honesty and transparency regarding the environmental impact of their business. However, in relation to RQ2, the process of conducting the EP&L, inspired Novo Nordisk to explore opportunities to reduce the environmental impact of the activities that were not directly related to the production of their products. In terms of influencing the environmental agenda within the company, the Programme Director reported a mind-set change in the company, stating that: "*the understanding has changed away from the stance that* '*environment is just something*, *which happens in production*'".

Being a company with high focus on sustainability, Novo Nordisk's suppliers were already required to document that their work was carried out in accordance with the laws and standards for environment, health and safety, labour and human rights, and business ethics. The EP&L provided additional knowledge to enhance this work with green supply chain management. Furthermore, the EP&L was an eye-opener on how much of the impact was related to Indirect spend. While initiatives within core activities related to Direct spend were already well integrated in the organisation, the field of Indirect spend would require new initiatives aimed at all suppliers, not only those directly linked to the core business, such as production of insulin and devices.

The EP&L provided more than just measuring impacts; it also served as a risk mitigation tool. As the Programme Director put it in the interview: "*We need to move away from only thinking about our own production*; *environmental regulations keep getting shrewder*, *which makes the whole value chain important*". Putting a monetary value on company externalities made the company aware of the risk of the external costs becoming internalised in the future. If, e.g., a global carbon tax were to be introduced (even though this was not seen as likely, but other means might trigger similar consequences), it would result in higher prices on products with a high carbon footprint. It would also influence Novo Nordisk's own production facilities and this knowledge could help encourage investments in green technologies and energy optimisation. Identified risks were moreover related to other environmental impacts, which, in the future, might influence investment decisions, e.g., where to build a new production site. Thus, even though the EP&L "only" served to measure impacts for one year, it contributed to inspire and suggest ways of working with sustainability in a business context in the future.

4.3. Case Study 3: Life Cycle Assessment of a Tanker Ship

The life cycle assessment (LCA) of a tanker ship was based on gathered data for five years of ship operation, extrapolated to represent the whole life cycle, which was assumed to be 20 years. Impacts from ship building and dry dock repairs were distributed over the operational lifespan of the ship. Further assumptions can be found in Kjær *et al.* [28]. Results showed that the dominant contributor to the carbon footprint of a ship was the fuel combustion during the use stage. In CO_2e, fuel combustion accounted for 80% of the impact. The second greatest contributor was extraction and production of the fuel, which accounted for 9% of the impact. Thus, only 11% of the carbon footprint was not related to fuel, but stemmed from the production and maintenance of the ship including the machinery and equipment on-board the ship, use of crew consumables including food, crew travel and use of services such as inspections, port services, yard service, *etc.* The overall result of the Life Cycle Cost (LCC) and LCA, divided into categories, are shown in Figure 6.

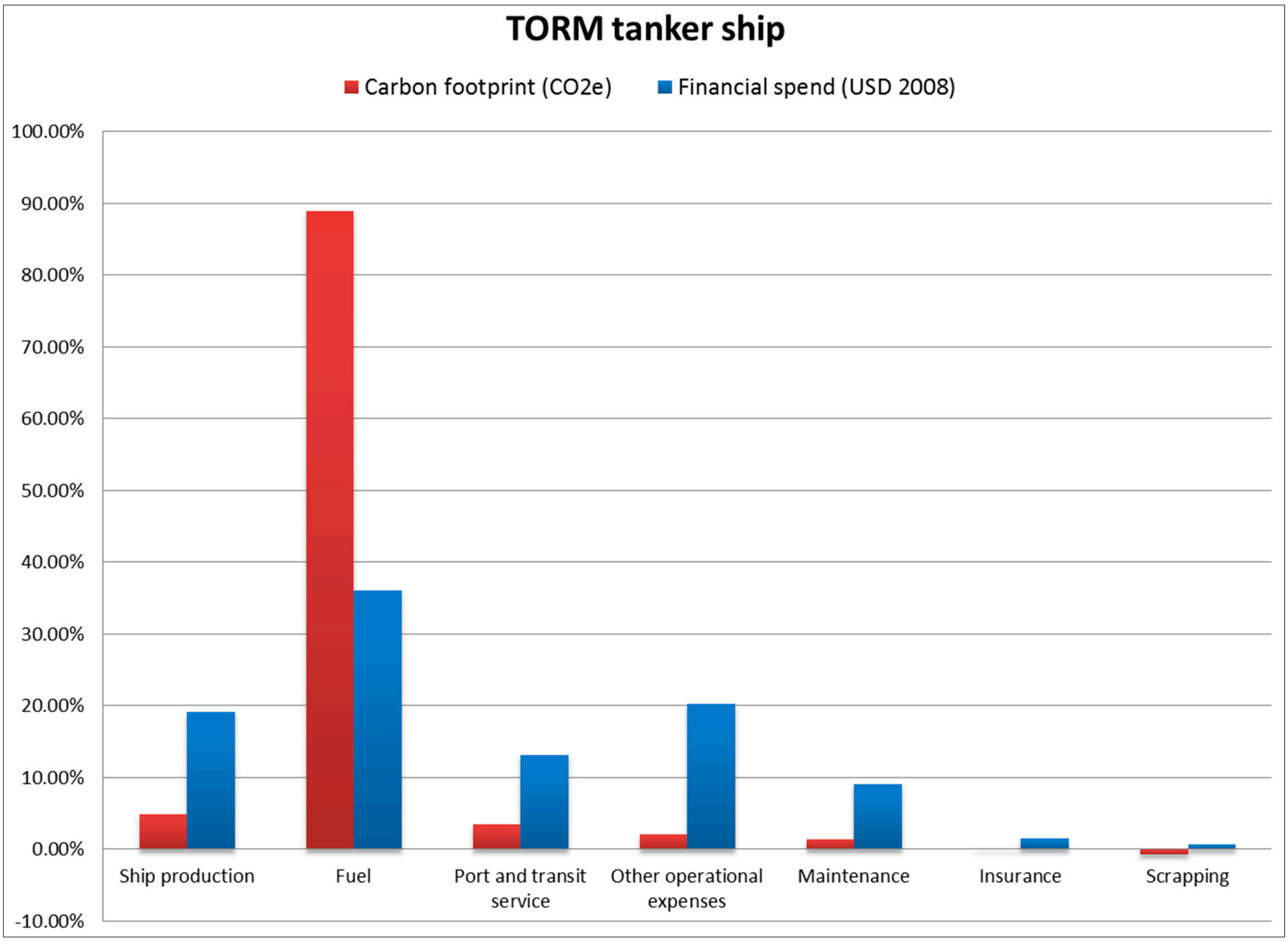

Figure 6. TORM tanker ship. Categories' relative share of CO_2e emissions and financial spend

The results showed that spend categories with high service content such as operational expenses had low CO_2e per USD. Port and transit services were somewhat higher due to the use of towage ships when in port. Scrapping resulted in net avoided or "negative emissions" to the environment, because the scrap was assumed to substitute virgin ore in the iron production. All costs were mapped as value added throughout the life cycle to avoid double counting [28].

In relation to RQ1, the EIO approach had the advantage that the LCC and LCA could be based on the same initial financial data. In contrast to the two other cases presented in this article, the indirect emissions constituted only a small part of the overall environmental footprint and, thus, the embedded uncertainty in the EIO model used to quantify these indirect impacts could be tolerated. Being closely related to cost savings, fuel efficiency was already high on the agenda in TORM. In relation to RQ2, it was not considered part of the company strategy to try and influence the indirect impact caused by suppliers, and in this sense the environmental agenda of the company did not change as a result of the analysis.

However, presenting the costs and environmental burden together showed where there were potential misalignments between the two and where there were risks of external costs being internalised in the future. In the case study, fuel accounted for 89% of the CO_2e but only 36% of the cost. With the likelihood of climate change continuing being an increased societal issue in the future, there could be a risk of fuel prices rising as a consequence of carbon taxes or other market-based measures. Thus, the analysis was used to discuss how the company could gain from increasing the focus on fuel savings, e.g., by investing in optimal maintenance, better quality ships, and on longer-term alternative energy sources. Strategies for reducing fuel consumption included changes in operational patterns (involving decreased speed), hull and performance monitoring, and technical retrofits. Since TORM was merely a ship operator and not ship builder, how the ships were designed or might be retrofitted for being energy-efficient would require close collaboration with suppliers. It was, however, not considered within the current scope to include supply chain related (indirect) impacts in reduction strategies. Potential collaboration would focus on how suppliers could help TORM reduce the fuel consumption of the ships.

5. Discussion

In this paper we discuss strengths and weaknesses of the EIO approach (RQ1) and how the approach might influence a company's environmental agenda (RQ2), including green supply chain initiatives. Two issues of concern were identified during the research, and are discussed in the following: uncertainty of the results (found as the main weakness in relation to RQ1) and integration with strategic actions (found as the main challenge in relation to RQ2).

5.1. Uncertainty

Uncertainty of the results depended on two aspects: the EIO model used and the data inputs available for the study. Model related uncertainties were: data age, geographic reach and sector aggregation. The applied model was based on data from 2003, and it was therefore assumed that the technology mix was representative of present consumption. The consumer price index was used to translate all spend to 2003 prices. However, the same general index was used for all types of products and services, which added to the uncertainty. In regard to geography, a modified version of the EU27 table was used to represent the Rest of the World (RoW). This especially could have influenced the results in case study 3, TORM, who have most of their purchases on the global market. Another model related weakness was the limited number of included elementary flows in the model. As an example, in case 2 (Novo Nordisk), another model was applied for calculating water use, because this was not included in the FORWAST model.

In regard to sector aggregation, the uncertainty depended on the match between the financial spend category and the EIO sector. When an EIO sector was chosen, it was assumed that the purchases could be covered by the average products in that EIO sector. However, if the spend category was very broad (e.g., "acquisitions", which could cover many product types), the uncertainty of selecting the right EIO sector was high. The same applied to the opposite case where a spend category was very specific (e.g., "coffee machines") but the EIO sector very broad (e.g., "Machinery and equipment", which contained coffee machines but also many other products). Thus, the best match would be when both the spend category and the EIO category were specific (e.g., the match of the spend category "medicine" and EIO sector "pharmaceuticals"). The next best match occurred when both the spend category and the EIO sector were equally broad, hence, it could be assumed that the spend category covered the same range of product types as covered by the EIO sector. Figure 7 illustrates the four different situations.

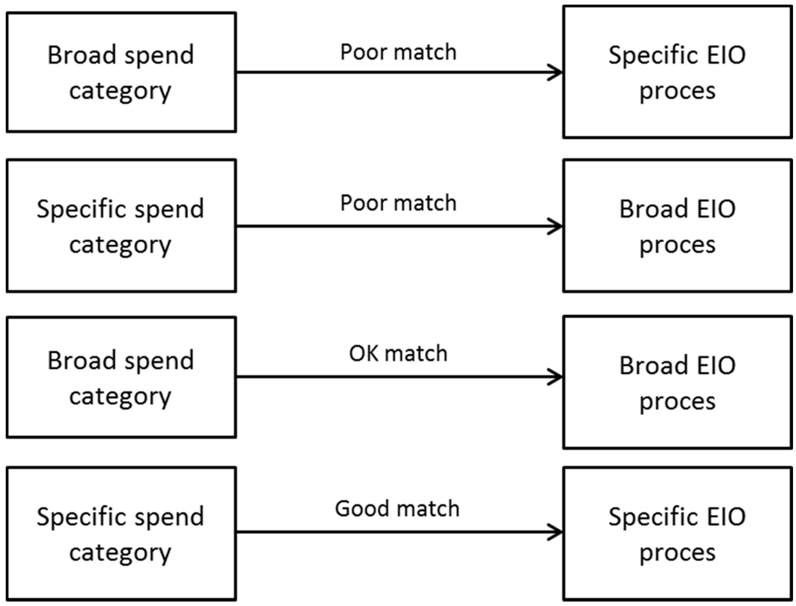

Figure 7. Matching spend categories and EIO processes.

In the case studies, the uncertainty was reduced by disaggregating both EIO sectors (through statistical data and hybridisation with more detailed data) and spend categories (e.g., by gathering data on supplier invoices). However, this process took time and was, therefore, only done on selected focus areas with high importance and/or high volume. The fact that the process of hybridisation can be time consuming and require expert knowledge is also confirmed by Ewing *et al.* [9]. However, one important prerequisite for the companies to implement changes was the ability to calculate the effect of potential initiatives and monitor the effect after implementation. Thus, the need for more detailed data on selected focus areas quickly arose. Data collection and analysis then became an iterative process with the aim of reducing uncertainty and improve the analysis framework to better represent the actual circumstances regarding the system being analysed.

5.2. Integrating Environmental Footprint Analysis with Strategic Actions

In all three cases, the environmental footprint screenings were conducted based on historic data, and the analyses were by nature descriptive studies with the aim of showing the relationship between direct and indirect impacts and identify hotspots, taking all upstream impacts into account. For case studies 1 and 2, the purpose of commissioning the study was furthermore to show external stakeholders that the companies were responsible and had high standards for environmental concern. This is supported in an expert review of the first EP&L conducted for PUMA, where the initiative was seen as an innovative, refreshing and honest corporate initiative [45]. As mentioned, one case company used the results in their compliance work, by reporting to CDP.

However, the question is if and how the analysis influenced or changed the companies' environmental agenda and broadened their scope. Case studies 1 and 2 showed that for these organisations and companies the amount of supply chain hidden impacts was very high compared to what was currently targeted in their reduction efforts. However, for case study 3, the case was quite the contrary and the company merely used the study to support their current strategy on reducing direct emissions. Thus, the current environmental agenda was only challenged in case studies 1 and 2. For these organisations and companies, getting numbers on the "hidden" impacts inspired them to start implementing actions aimed at the indirect impacts caused by the supply chain. However, we also experienced that it was a communicational challenge to explain the results in a positive way in order to inspire actions. Arguments against included: perception that these impacts were outside the company's sphere of influence, changes would be difficult to implement, and that it would be difficult to monitor the effect of the actions. For case study 1, employees responsible for climate change mitigation had previously focused primarily on energy consumption and transport. Addressing impacts related to purchased goods and services required new and different initiatives. It involved new stakeholders within the organisations, including management, procurement and financial accounting. This indicates that for companies to be able to use environmental footprints proactively, a coordinated effort between departments and other influencing initiatives such as supply chain management and CSR strategies are needed. This is supported in the expert review of the EP&L account for PUMA, where it is stated that it is important to align the analysis with other efforts and work together as part of a bigger strategy initiative [45].

5.2.1. Impact Reduction Strategies

Using the EIO approach to calculate the impact based on financial data provided the opportunity to relate the calculated impacts to the financial spend. This relationship would however only be relevant in cases with options to switch from high carbon intensive to low carbon intensive uses. As an example, switching from spending money on food products to, e.g., medicine in hospitals would hardly make any sense. Focus was, therefore, on how consumption within each category could be optimised. Showing the relationship between carbon footprint and financial spend was however interesting, as it highlighted the fact that more service-intensive uses had lower impacts per money spend than product-intensive uses. The case studies presented in this article, as well as other studies, confirm the fact that services are less carbon intensive per monetary unit spend than physical products [46].

An EIO-based screening will highlight environmental hotspots totally independent of other influencing factors, such as sphere of influence and political/management attention. However, as we saw in the case studies, the "hard numbers" were only one of many considerations to take into account when prioritising initiatives and efforts within the organisation's sustainability agenda. For example, in case study 1, even though hospital food was chosen as a focus area, it was not considered feasible to cut down on the amount of meat for nutrition reasons. Instead, reducing food waste and using food waste for biogas production were chosen as feasible strategies. When the different feasible actions were identified, the reduction potential could be calculated and key performance indicators formulated.

Looking at actions aimed at reducing supply chain impact, the companies in case studies 1 and 2 where initially starting to integrate performance measures in their green purchase and supply management. In the following we look at the literature on green supply chain management and discuss how the environmental footprint account might be integrated.

5.2.2. Integration with Green Supply Chain Management

According to Seuring and Müller [5], governments/authorities, customers, and other stakeholders, including NGOs, place a range of "triggers" on the focal companies (buying firms) to increase their involvement in green/sustainable supply chain management. The authors divide mitigation strategies into "supplier management for risk and performance", where standards and management systems, such as ISO 14001, as well as supplier evaluation schemes, play central roles, and "supply chain management for sustainable products," where life cycle management is an essential activity [5]. Both strategies might be supported by an environmental footprint analysis, putting quantitative measures into play. Supply chain management in general might involve all suppliers to the company, and thus relates to the accounting approach of case studies 1 and 2. "Supply chain management for sustainable products," evolves around the life cycle of the product or service produced by the company, and relates to the life cycle assessment approach demonstrated in case study 3.

Risk avoidance is often a main driver for supply chain programs [47], and this was also seen in the case of Novo Nordisk. Using the EIO approach for the purpose of an EP&L provided an understanding of where hotspots were located within the supply chain and was, thus, seen as a risk identification tool. As also stated in the expert review of PUMA's EP&L, the account "provides an early view of emerging risks, enabling businesses to respond strategically to protect and enhance shareholder value".

Kogg and Mont [6] distinguish between three approaches to how companies address sustainability aspects in the supply chain: de-selecting products or suppliers, who does not live up to a certain standard; indirect influence through compensation schemes, NGO support, *etc.*; and direct approaches, such as setting up specific requirements, motivate, support and enable sustainable development by inter-organisational collaboration. De-selecting products or suppliers, which do not live up to a certain standard, does not necessarily reduce the environmental impact, since the suppliers might simply deliver to another customer instead. Likewise, the actual effect of using compensation schemes and supporting NGOs can be very difficult to measure. It can thus be argued that a company will only make true measurable changes through directly influencing the suppliers. In case study 2 (Novo Nordisk), supplier demands had so far focused on compliance and reporting of procedures. This is supported by Kogg and Mont [6] who state that companies are more likely to report in terms of procedures and steps they have undertaken for dealing with suppliers, rather than reporting on the actual outcomes in terms of reductions of environmental and social impacts. Thus, measuring and monitoring actual reductions of environmental impact is still not common practise. One famous case of supply chain engagement is Walmart, who experienced how simply asking suppliers to measure, report and state a reduction target on their corporate greenhouse gas emissions led to improvements [48].

6. Conclusions

Companies are faced with a pressing need to address the environmental impact of their operation. For many companies, a large share of the environmental impact is embedded in the upstream supply chain, requesting the company to act as a responsible customer and implement green supply chain management initiatives. In this article we have applied the EIO approach for corporate and product environmental footprint accounts, including the entire supply chain. The first research question was:

RQ1: What Are the Strengths and Weaknesses of the EIO Approach?

We conclude that the greatest strength of the EIO approach was that it made analyses of the total supply chain impacts feasible and enabled identification of hotspots in both direct and indirect operations. The possibility of using readily available financial data as starting point made a first screening fast and relatively easy. For corporate footprint accounting, yearly financial accounts together with supplier invoices provided the data input. For LCAs of products, Life Cycle Cost (LCC) inventories can do the same, as also demonstrated by Junnila [12]. Not having to deal with truncation issues and risks of leaving out potentially important contributors, the approach provided an opportunity to prioritise all environmental release hotspots equally—independently of where in the value chain they arose. However, uncertainty related to the modelling approach was identified as an issue in both literature and the case studies. When addressing important focus areas, EIO models need to be optimised by disaggregating relevant sectors and hybridising with process-based data in order to gain more representative results. Future development of EIO models should have the following focuses:

- They should have a global scope, thus being multiregional to account for geographical differences.
- They should include the elementary flows needed to support what is of environmental concern.
- They should contain a wide range of both aggregated and disaggregated product groups/industry sectors in order to enable the best match with available data for the system being analysed.

In the newly announced Exiobase v2, Input-Output tables are integrated with life cycle assessment and mass flow analysis, and the database includes trade balanced supply-use tables for 43 countries and five Rest of the World regions [49]. This provides a strong platform for creating analyses on various levels ranging from environmental footprint of nations to corporate footprints and environmental assessment of products [50]. Increasing the level of detail of product groups and sectors will strengthen the model even further. Hybridising the model might come from integration with more detailed LCA databases, such as EcoInvent, but might also be facilitated through projects where industries make data available in order to gain a stronger foundation for the analyses aimed at their specific activities.

Moving from evaluating the approach as a method towards application of the results, the second research question was:

RQ2: How Does Application of the EIO Approach Influence the Companies' Environmental Agenda?

The case studies showed that the approach provided a good foundation for identifying where to prioritise when looking for actions that could improve the environmental profile of the system under analysis. For the companies and organisations with large upstream environmental footprints, the analyses supported advancing their sustainability agenda to include supply chain impacts. When combined with monetary valuation of impacts as in an EP&L, the analysis was also reported to serve as a risk mitigation tool. The approach seemed less relevant for high-energy consuming products, such as ships, where focus necessarily must be on reducing the impact within direct operation. Nevertheless, also in this context, the approach provided an overview and put all contributors into perspective.

However, the magnitude of environmental impact was not the only criteria when the companies selected focus areas for their sustainability work. Other influencing factors included: sphere of influence, political focus, supplier relationship, and ability to monitor. More work is needed on integrating environmental footprints with strategies on green supply chain management and green purchasing, both in regards to organisational implications and in regards to calculating the actual environmental effect of different actions. In this regard, there is a need for exploring how (hybrid) EIO models can be used proactively to support decision-making in the development of more sustainable products and services, and may be used as a tool to support investment decisions.

Lastly, outside the academic community, development of guidelines for practitioners are needed. Huang *et al*. [2] states that one of the reasons why EIO methods are lacking behind is the lack of expertise available to assist companies to undertake EIO studies.

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Author Contributions

Louise Laumann Kjaer and Niels Karim Høst-Madsen worked as consultants in NIRAS for several years and have developed the approach described in this paper together with Jannick H. Schmidt from 2.-0 LCA consultants. The work on corporate carbon footprint accounting for the three Regions was led by Louise Laumann Kjaer and Niels Karim Høst-Madsen. Niels Karim Høst-Madsen led the project on the Novo Nordisk EP&L. Louise Laumann Kjaer conducted the study on the TORM tanker ship. Jannick H. Schmidt played a central role in developing and refining the FORWAST model and also served as a reviewer of the conducted analyses. In writing the article, Louise Laumann Kjaer led the work and conducted the literature review needed to write the paper. Tim C. McAloone supervised the process and contributed to the writing and proofing of the paper. Jannick H. Schmidt contributed to the description of the FORWAST model and the validity of the conclusions made. Niels Karim Høst-Madsen contributed to the description of the methodology and the case study results. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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