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Total CO_2 Calculation in SCM

Christian Wick [1], Laura Koppers [2], Matthias Klumpp [2]

[1] NOWEDA eG Apothekergenossenschaft
Heinrich-Strunk-Straße 77
45143 Essen, Germany
chr.wick@congstar.de

[2] Institute for Logistics and Service Management (ild)
FOM University of Applied Sciences
Leimkugelstraße 6, 45141 Essen, Germany
matthias.klumpp@fom.de

Abstract

Up to the present the concept of supply chain management (SCM) is predominantly known for revealing cost saving potentials at corporation's interfaces from the point of origin to the point of sale. Often this perspective does not consider environmental needs within the supply chain (SC). Climate changes and other natural disasters due to global warming and air pollution are the consequences. Therefore a number of topics concerning these aspects have recently been taken into theoretical and practical account. They are often discussed under keywords as e.g. 'Green SCM', 'Sustainability' or 'Corporate Social Responsibility'. In order to gain competitive advantages all corporations in a SC have to consider the development of sustainable strategies, i.e. common SC strategies have to be developed and approved. It is assumed that in the future only those market participants will succeed who implement such strategies by translating and enacting them in an operational context.

One specific tool to communicate the corporation's environmental impact to the end customer is the so called 'carbon footprint': It illustrates the total amount of CO_2 or CO_2 equivalent emissions caused by a single product or service. The way of estimating respectively measuring all emerging greenhouse gases along the entire SC remains largely unanswered in theory and practice. This paper provides a theoretical approach consisting out of six stages. Concluding the requirements for further research and evaluation are discussed.

Keywords: Green SCM, CO_2 Calculation, Carbon Footprint, Sustainability, Corporate Social Responsibility

1. Introduction

The *concept of SCM* is predominantly discussed as a methodology to reveal cost saving potentials on the one hand and to show opportunities for an increase in revenues on the other hand [1, 11, 24, 30]. Therefore all members of an entire SC, defined as a virtual entity that "… encompasses all organizations and activities associated with the flow and transformation of goods from the raw materials stage, through to the end user, as well as the associated information flows" [11], get together in any kind of cooperation.

Since a couple of years, *trends* exceeding cost- and revenue-thinking have become of higher interest revealing new SC strategies. Due to the fact that a limited and short-term economic point of view does not meet the interests of all stakeholders, further considerations have to be taken into account. *Environmental needs* gained more attention in literature and practice. As e.g. climate changes caused by *global warming* lead to retreating glaciers, rising sea-levels, heat waves and other threats, corporations (will) have to develop *common* strategies in order to contribute to an essential *sustainable development* of their economic activities [17, 37].

The rising impact of this development is reinforced by an *intensification of existing and an establishment of new laws* [16] passed by authorized institutions like national governments or the European Union (EU). As probably a great many countries, corporations and citizens are not voluntary assuming responsibility for their own economic behaviour, comprehensive conventions are essential. The perhaps most known convention concerning the decrease of worldwide *greenhouse gas emissions* (GHG emissions), the *Kyoto Protocol*, was passed by the participating countries within the 3rd United Nations Climate Change Conference (UNCCC) in Kyoto (Japan) in the year 1997 organized by the United Nations Framework Convention on

Climate Change (UNFCCC). It reveals that 37 industrialised countries and the EU endeavour efforts to reduce their GHG emissions by 5 % on average compared to 1990 [32]. There seems to be a widely spread consensus for the need of further decrease of GHG emissions. Although the recently (December 2009) hold UNCCC in Copenhagen did not manage to develop a replacement for the 2012 ending Kyoto Protocol. The passed *non-binding Copenhagen Accord,* with its objective to limit the increase of global warming to below 2 degrees Celsius till 2050 in relation to the pre-industrial level, is regarded to be a small step towards more responsibility in the context of sustainable development [33].

Due to the rising trend of international *division of labour,* interconnected with a corporation's concentration on its own *core competencies* [22, 30], all interdependent processes along the entire SC have to be checked, up-dated or replaced in order to fulfil sustainable requirements. This often leads to the need of redesigning non-sustainable activities between the point of origin and the point of sale (POS) – in an environmental context often described by postulations as e.g. 'greening the supply chain' [2, 17, 25, 27, 29]. Because corporations are often afraid of rising costs and other disadvantages due to an implementation of sustainable strategies it can be hypothesised that "… early or first movers, following the idea of Schumpeter's pioneer profit, can achieve financial gains by introducing new goods or methods of production as innovative action results in monetary benefits" [38]. In other words: a corporation's economical success, e.g. rising shareholder value (SHV), can be influenced by the (early) adoption these sustainable, particularly green, issues [9, 14, 16, 27, 29].

However, not only financial subjects are of interest. The continual improvement of such intangible assets as e.g. *corporate image* has to be kept in mind as well. Corporations like Deutsche Post World Net/DHL or Nike pronounce already their contributions to sustainability through *sustainability reports* [19, 27]. Another current example is the decision of McDonald's Germany to change its logo colour from red to green expressing respect towards environmental needs [13]. Time will show if this statement can be interpreted as a serious effort to effectively implement environmental-friendly actions [18].

It is likely that those market participants, who have already implemented or are going to implement green thinking, will have significant competitive advantages compared to latecomers. Thus a short-term view has to be replaced by a long-term view. This paper puts the focus on global warming by presenting an effective methodology of how to calculate the SC related impact of GHG emissions responsible for this effect.

2. Sustainability and Corporate Social Responsibility

With global warming two strategies are often discussed: 'Sustainability' and 'Corporate Social Responsibility' (CSR). In the following their main characteristics will be described and for each strategy, including possible sub-strategies, a basic definition will be stated.

Sustainability meets the interests of future generations ('long-term view') [22]. Therefore it is e.g. not acceptable to waste natural resources like forests and mineral fuels or land, water and air. But this consideration is just one dimension sustainability consist of – perhaps the most famous one. Altogether three major dimensions are linked with the strategy of sustainability: economic, environmental and social dimension [10, 14]. The *economic dimension* refers to factors as economic growth, cost savings and profits. Usage of natural resources and prevention of several forms of pollution are only two examples concerning the *environmental dimension*, while the *social dimension* takes factors as education, living standards and social integration into account [14]. These three dimensions depend on each other more or less [10]. Summarising the following wide-spread and well-accepted working definition of sustainability, created by the United Nations World Commission on Environment and Development (UNWCED) in their 1987 published report "Our Common Future", also known as the "Brundtland Commission Report", is provided [41]:

“Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

Up to the present a number of *sustainable strategies* have been integrated into SCM considerations. Examples are the following:

(1) *Reverse logistics* refer to those activities flowing up the SC from the POS respectively the point of consumption to the point of origin. Corresponding processes are for instance *recycling* and *disposal* [10, 19, 28, 30, 37].

(2) Strategies like *closed-loop SCs* and *extended producer responsibility* (EPR) are closely linked with reverse logistics processes as they include all reverse actions next to their primary down-flowing tasks. This means that there is an *all-encompassing responsibility* (from ‘*cradle to reincarnation*’) for each product or service manufactured by SC’s participants, i.e. all consumer related actions are completely integrated, too [4, 10, 19, 29, 37].

(3) The *triple bottom line* (TBL) approach is based on the three dimensions sustainability consists of. ‘*Profit*’ (economic), ‘*planet*’ (environmental) and ‘*people*’ (social) are the dimensions an entire SC has to take into account. This strategy aims at the measurement and reporting of success achieved by various processes and values (re-) designed in order to become a sustainable corporation respectively SC [10, 35].

(4) *Product stewardship* and *eco-efficiency* relate to research and development (R&D) of *ecological proper products and services*. The objective is to involve the know-how of all parties representing a single SC, in order to improve environmental and simultaneously efficient product and service standards. *Reverse logistic processes* also belong to product stewardship considerations [10, 16, 29, 30].

(5) *Green SCM* can be interpreted as a broader version of the original SCM that is *incorporating environmental affairs*. Therefore ecological considerations and external regulations have to be taken into account, i.e. *existing SC designs have to be analysed and changed or replaced by new green SC designs* [10, 17, 29].

(6) *Carbon footprints* represent particular *tools measuring the total amount of carbon dioxide (CO_2) and other GHG emissions* caused by certain products, services or processes. Thus this strategy contributes to a *holistic view* and seems therefore to be useful for further considerations within this paper (cp. chapter 3) [7, 10, 26].

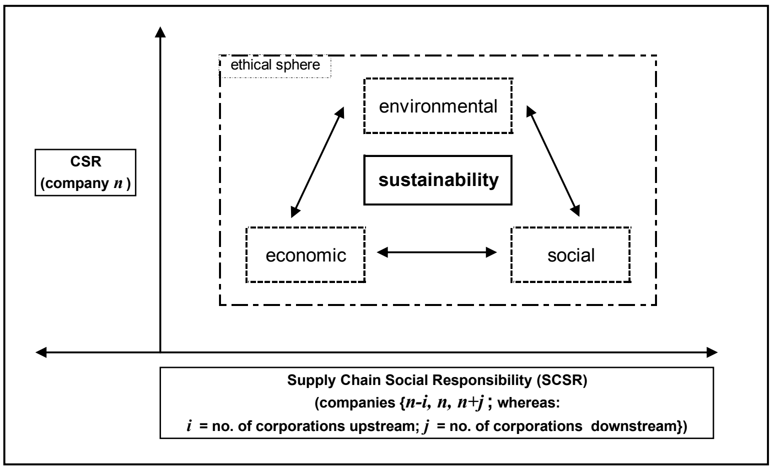

Figure 1. Sustainability and Corporate Social Responsibility.

CSR is a broad strategy heavily *based on sustainability*, also regarding the three dimensions of economic, environmental and social belongings. It goes beyond that, by appealing to the responsibility of any kind of corporation. Because corporations can be interpreted as social systems consisting of individual people and being permanently linked to other systems as e.g. the environment they should demonstrate corresponding respect for their surroundings. Derived from this consideration CSR represents the *voluntary commitment to incorporate sustainable belongings into a corporation* [10]. Thus corporations do not only fulfil legal requirements ('compliance') but they also establish an own corporation-referred ethical codex "… consistent with the morals and values of society …" [14].

Due to division of labour SCs often act global. This thinking leads to the postulation that corporations from industrialised countries should take care of all conditions their partners deal with in less-developed countries. And therefore only those suppliers who ensure to respect the rules of CSR can be chosen as strategic partners [10]. If all corporations along an entire SC have introduced CSR, *Supply Chain Social Responsibility* (SCSR) is installed. The assumed interrelations between sustainability and CSR for a single corporation and along the entire SC are shown above within figure 1. The following working definition made by the World Business Council for Sustainable Development summarizes CSR [39]:

> "Corporate Social Responsibility is the continuing commitment by business to behave ethically and contribute to economic development while improving the quality of life of the workforce and their families as well as of the local community and society at large."

3. Carbon Footprint

Although the term 'carbon footprint' can be often read in academic literature there is no common understanding of how to define it. This paper discusses its main characteristics and argues why it is an effective tool for calculating total GHG emissions along the entire SC.

Essentially the carbon footprint represents a new stage of development concerning the so called '*ecological footprint*'. First revealed by WACKERNAGEL/REES the ecological footprint is understood as a set of instruments assessing human's demand for environmental issues [34]. As there is an inevitable *use of biologically productive land and water areas* all over the world, shortage of resources appears consequently. The ecological footprint has become a measure *indicating the impact of human activities by relating to the areas needed per capita* [26, 34]. Thus it defines the economical influence on certain ecological areas used to produce resources and store waste. Introducing the consideration that nature particularly absorbs GHG emissions the definition of carbon footprints starts [36].

First of all, it needs to be clarified that when speaking about carbon footprinting in SCM not only CO_2 emissions have to be taken into account, but *all relevant GHG emissions* [3, 7, 26]. The most harmful gases pushing global warming and constituting the largest impact on this effect have been summarized in the Kyoto Protocol [32]. Non-carbon emissions can be converted into *carbon dioxide equivalents* (CO_2e) in order to achieve proper calculation values. Therefore conversation factors are necessary. The probably most used value is the '*Global Warming Potential'* (GWP) defined by the Intergovernmental Panel on Climate Change (IPCC). It indicates the relative contribution of a GHG to global warming within a determined time period (e.g. GWP_{100} = 100 years) compared to the effect CO_2 causes (cp. table 1) [3, 7].

GHG	chemical formula / abbr.	conversion factor: GWP_{100}
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298
Hydrofluorocarbons	HFCs	124 - 14,800
Perfluorocarbons	PFCs	7,390 -12,200
Sulphur hexafluoride	SF_6	22,800

Table 1: Footprinting Relevant GHGs and Their Global Warming Potential(s). [3, 32]

Second it has to be decided *on which scale GHG emissions should be included* calculating carbon footprints. Predominantly not only direct emissions are measured but indirect emissions, too. The main characteristics and differences of both forms are as follows: *Direct emissions* always depend on system boundaries, i.e. usually a single corporation. All GHGs a corporation causes itself due to e.g. heating, production processes and exhaust gases in transportation are consequently defined as direct ones. *Indirect emissions* on the other hand include those GHGs that occur outside a single corporation, although they correspond to the use of energy or raw materials within the corporation. This means that GHG emissions have already been generated due to previous processes outside the system boundaries. Consequently preliminary products or services needed for further processing are usually already charged with certain GHG emissions [26].

In order to *accurately define system boundaries of direct and indirect GHG emissions* the '*concept of scope*' provided by World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI) can be adopted. It consists of *three scope categories standardised to achieve transparency and ensuring avoidance of double counting problems* by different corporations. *Scope 1* represents all direct GHG emissions caused by "… sources that are owned or controlled by the [regarded] company …" [40]. *Scope 2* then contains indirect GHG emissions generated by purchased electricity. Physically these GHG emissions are set free outside the defined corporation's boundaries. Finally *scope 3* refers to all other indirect GHG emissions caused by sources that are not under control of the corporation, e.g. GHG emissions due to product use by the end consumer [40]. These considerations reveal that for measuring the total impact of GHG emissions caused by certain objects along the entire SC it is essential to factor in direct and indirect emissions.

Third it is necessary to establish a common understanding of what *reference parameters* should be used for measurement. In contrast to ecological footprints, which were presented at the beginning of this chapter, reference parameter is no longer an ecological land area but a *particular product or service* [36]. As they more or less fulfil all human needs emerging at the POS it can be argued that both of them seem to be suitable objects for measuring total GHG emissions caused by industrial and human activities. One famous methodology to calculate a product's impact on nature is the so called *life-cycle assessment* (LCA), often stated as *life-cycle analysis*, too [8, 20, 36]. This methodology provides a *holistic view* of certain products or services by regarding their full life-cycles, i.e. '*from cradle to grave*' [5, 26, 35]. But in this context one problem occurs [26]: How to measure GHG emissions caused by the end consumer due to the use of certain products or services? After leaving the POS-threshold corporations do not have any more influence on their goods. However, it seems to be necessary that average values get already estimated in order to be included in the total emission amount providing global figures. Finally all corresponding *processes and activities* have to be taken into account trying to measure their total impact regarding generated GHG emissions. This makes it once more essential to involve all partners as there are lots of interdependencies along the entire SC. Therefore a limited view on only just a few corporation interfaces misses out.

In order to achieve proper calculation it is helpful to use special software tools as e.g. *carbon calculators* [12]. Integrated in a corporation's *environmental information system* emission data and further belongings can easily be managed in order to achieve transparency concerning CO_2 calculation. This leads to the consideration that it might be necessary to establish a certain *emission accounting department* analogous to classical financial accounting entities [12]. But there always has to be a linkage of all SC partners as it is essential to generate SC-wide data in order to reveal the global CO_2 impact of a product or service. If transparency exists, process and product improvements can be done and the (low) amount of GHG emissions caused by certain products or services could be integrated into a corporation's *marketing strategy* related to the end consumer and other stakeholders. Thus e.g. image benefits and increasing sales can be achieved. But these are only two economical advantages carbon footprinting stands for. Summarizing the considerations on carbon footprints the following working definition is suggested:

A carbon footprint is a tool for communicating environmental impacts of certain products (or services) to the customer. Measuring all direct and indirect GHGs in terms of CO_2e it reveals the total emission quantity polluting our nature. Thus all activities and processes along an entire SC are taken into account ensuring that the product's entire life-cycle is included 'from cradle to grave'.

4. Calculation Methodologies

Before presenting considerations of how to successfully measure total GHG emissions along the entire SC existing methodologies will be classified in order to point out essential requirements for calculating a carbon footprint. Based on current literature two main calculation methodologies can be identified. These are (a) an *input-output analysis* and (b) a *process analysis*. Moreover it is possible to (c) combine both methodologies (*hybrids*) in order to synthesise the advantages that each type of analysis provides.

(a) The *input-output analysis* starts with a collection of *macro-economical data* provided by governments or non-governmental associations as e.g. the UN. Such information segmented according to different sectors is then used by *allocating cumulative GHG emissions* of a nation or other territories to single SCs, corporations and finally certain product or service categories. In order to achieve a proper allocation of GHG emissions *adequate allocation keys* must be identified. In the majority of cases the *created values* of activities or processes, i.e. generally revenues are chosen. As this recursive calculation methodology largely depends on estimations and allocations it probably does not lead to a fair problem solution. Otherwise it seems to be quite easy referring to such aspects as e.g. labour-intensity and expenditure of time. And the expected research costs should be on lower level, too. Finally this *top-down approach* provides *limited options revealing a fair and realistic carbon footprint* due to a loss of detailed information [12, 26, 35, 36].

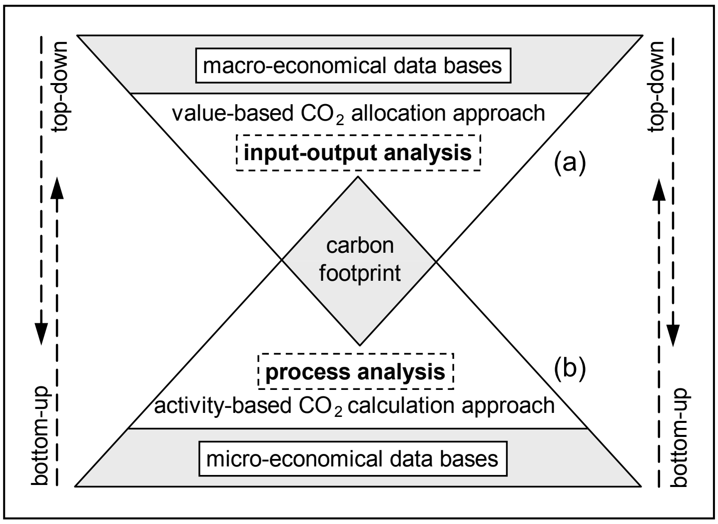

Figure 2: Interrelation of Presented Calculation Methodologies.

(b) *Process analysis* on the other hand is characterised by a *bottom-up approach* [36]. Therefore it is necessary to identify all processes that cause GHG emissions both within a corporation and even more important *along the entire SC*. As there are lots of interdependencies among inter-corporate activities it has to be ensured that *system boundaries* are *de-*

fined explicitly. Otherwise the problems of *under- and double- accounting* could occur [3, 26, 36]. After all processes have been mapped, their total impact on global warming has to be measured. If this it not possible in all cases, as e.g. due to the possibility that a certain product may be used in completely different ways or over varying time periods, *reference values, i.e. generic values,* are needed [26]. The final step is to sum up all GHG emissions set free due to manufacturing a certain product or service. But as already stated earlier in this paper, it is important to include *GHG emissions caused by use, waste and further activities* which occur after products or services have left the POS, too. Otherwise total GHG emissions caused by a single product or service could not be specified. This methodology is *closely linked* to *life-cycle assessment* (LCA) already discussed and standardised by such organisations as e.g. the British Standards Institution (BSI) (UK) [3], the Carbon Trust (UK) [3], the Department for Environment, Food and Rural Affairs (DEFRA) (UK) [3], the International Organization for Standardization (ISO) (CH) [20], the World Business Council for Sustainable Development (WBCSD) (CH) [39, 40] and the World Resources Institute (WRI) (USA) [40]. As process analysis is based on *micro-economical data* it can be regarded to be *more complex and comprehensive* than (a). This probably implies high labour- and time-intensities leading to rising research costs [26]. But in order to reveal accurate results concerning GHG emissions of certain products or services this methodology seems to be more appropriate. Considerations made by above-mentioned organisations underline this assumption. The following work is based on (b).

5. Total CO_2 Calculation Model in SCM

Trying to conceptualise previous considerations on total CO_2 measurements in SCs, a *six stage approach* is presented revealing a comprehensive calculation model: After the core processes have been identified segmentation into sub-processes and process elements is carried out. For each process element a CO_2 driver has to be detected before the total amount per unit of the CO_2 driver is measured (field research) or estimated (desk research). Afterwards the total CO_2 amount caused by an entire sub-process is calculated. Finally all GHG emissions of the needed sub-processes will be aggregated before the final sum of all GHG emissions is divided by the number of observed products or services. Thus the model is based on a *process-perspective* equal to the concept of SCM. It also integrates essential considerations according to *PAS2050 of BSI* [3]. In order to get a rough methodical overview the following figure 3 illustrates main ideas extensively explained within the following passages.

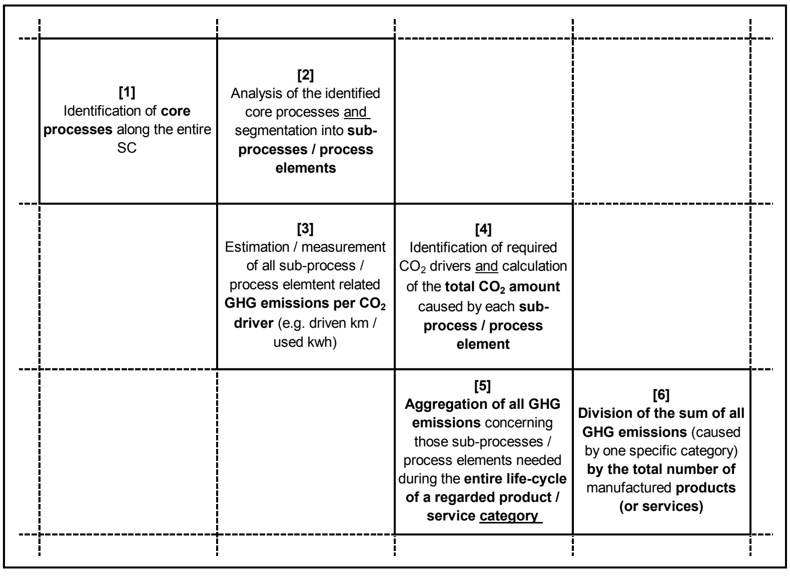

Figure 3: Footprint of a Process Cube Approach to Total CO_2 Calculation in SCM.

The first stage towards total CO_2 calculation in SCM is to identify all *core processes* both within a single corporation and along the entire SC. Thereby a process can be defined as an *irreversible sequence of connected activities* made up of its key elements 'input', 'throughput' and 'output' [23]. This point of view is now replacing the traditional section- or division-based one. Core processes always reveal an output corresponding to corporation-external consumers while *support processes* refer to internal activities. A known and wide spread accounting tool is *activity-based costing*. Based on its main characteristics, as e.g. identifying and analysing process categories and cost drivers, CO_2 measurement is done within this model.
In order to *develop a common understanding of core processes* SC partners have to *discuss and describe all of them* needed escorting a product or service *from cradle to grave*. Thus partners should be able to reveal *idealised and standardised process categories*. One appropriate way to do so is the implementation of frameworks as e.g. the '*Supply Chain Operations Reference' model (SCOR)* [31]. Developed by the Supply Chain Council, an US non-profit organisation, it consists of *four process levels* hierarchically build up. The '*Top Level*' (level 1) differentiates between the following process types: (a) *Plan*, (b) *Source*, (c) *Make*, (d) *Deliver* and (e) *Return*. On the '*Configuration Level*' (level 2) each top-level process can be described in more detail by generating up to 30 *process categories*. Then the '*Process Element Level*' (level 3) is especially used to *describe and define single process components, assess process performance metrics* and *establish best practices*. Finally the '*Implementation Level*' (level 4) consists of *decomposed process elements* in order to *develop implementation strategies*. Level 4 is not explicitly included in the considerations of the SCOR model [24, 31]. Thus this framework carries out a top-down disaggregation concerning all SC processes.
As this papers focuses on core processes ('*operative businesses'*) for calculating carbon footprints, only SCOR's top-level processes (b), (c), (d) and (e) are necessary for further considerations. The planning activities have to be neglected in order to become not too complex. Thus GHG *emissions caused by administrative activities* as e.g. R&D, accounting and sales should *be excluded* as it very costly to measure and allocate them correctly ('*cost-benefit ratio').* Referring to BSI, calculation boundaries, i.e. which GHG emissions should be neglected due to complexity, are e.g. those regarding immaterial emission sources sharing less than 1 % of the total CO_2 amount of one specific product or service. Further aspects not to include are human inputs and the transport of end consumers to POS [3]. In order to include all GHG emissions set free while *using a product or service* another core process has to be introduced: '*Consumption*'. This leads to *five core processes* (P_{total}): *Source* (S), *Make* (M), *Deliver* (D), *Consumption* (C) and *Return* (R). In a mathematically formalised way this enumeration can be illustrated as follows:

$$P_{total} = S;M;D;C;R\}. \quad (1)$$

Analogous to above-mentioned SCOR model the second stage to calculate the total CO_2 amount of products or services within SCs (*Stage 2*) implies *analysing all identified core processes in detail*. Then these processes have to be *disaggregated* in order to *reveal process categories* (SCOR model – level 2) and *process elements* (SCOR model – level 3) as described by the Supply Chain Council [31]. Moreover it seems to be recommendable to *map all process elements* concerning the regarded product or service life-cycle as e.g. supposed by BSI [3]. Thus all *interdependencies* can be made more *transparent* for all SC members. In order to be afterwards able to arrange *GHG emission benchmarks based on process elements* it is again necessary to establish a common understanding of process definitions within different corporations, i.e. *volume and content* for each process element has to be checked and systematised. Mathematically we can now define P_{total} as the sum of all *i* process categories (subprocesses) belonging to *S*, *M*, *D*, *C* and *R*:

$$P_{total} = \sum_{i=}^{n} S_i + M_i + D_i + C_i + R_i) \qquad \forall \qquad i,n \in I\sqrt{}^{+}. \tag{2}$$

Furthermore single process elements might be illustrated by small letters representing their corresponding process categories and the top-level processes as follows:

$$P_{total} = \sum_{i=}^{n} s_i + m_i + d_i + c_i + r_i) \qquad \forall \qquad i,n \in I\sqrt{}^{+}. \tag{3}$$

On the third stage *measurement or estimation of single GHG emissions* caused due to the usage of certain sub-processes respectively its elements takes place. It is primary necessary to *identify responsible CO_2 drivers*. As e.g. *delivery* is linked with the use of different transport modes (rail, road, sea or air transport) the total amount of covered kilometres (km) or ton kilometres (tkm) could be taken in order to provide SC-wide standardised calculation units [3, 15].

Next it needs to be decided whether corporation and SC corresponding data concerning a certain product or service should be *measured (field research / primary data)* or *estimated (desk research / secondary data)* [3]. This must be decided individually as the case arises. If corporations wish to reveal the most correct data then field research has to be done. Otherwise, if only rough figures are needed, a calculation based on desk research may be adequate. As there is often no other choice, *intermediates combining both research categories* have proven to be useful [26]. Moreover they tend to fulfil economic requirements especially those concerning *cost-benefit ratios*. As e.g. GHG emissions caused by a heavy good vehicle can be measured quite accurate, those GHG emissions caused by the use of a certain product or service often vary significantly due to different consumer behaviour [26]. At the end of stage 3 (a) *the main CO_2 drivers are identified, (b) analysed and* (c) *measured or estimated calculation values for all process elements are provided.* Values according to (c) can be expressed mathematically as vector ($\vec{u}$) indicating the CO_2 amount caused by a single CO_2 driver i concerning all sub-process elements s, m, d, c and r:

$$\vec{u} = (u_{si;}; u_{mi}; u_{di}; u_{ci}; u_{ri}) \qquad \forall \qquad i = 1,\ldots,n) \in I\sqrt{}^{+}. \tag{4}$$

The fourth stage implies calculating the *total CO_2 amount caused by each sub-process element*. As this can only be done if *all required CO_2 drivers have been identified* further data research revealing the *absolute number of demanded CO_2 driver units per process element* is necessary. The result should be a listing of all measured or estimated numbers as e.g. in the following format: 800 run kilowatt hours (kWh) for m_i, 750 driven kilometres (km) for d_i, etc. Mathematically we can illustrate this in the form of a vector ($\vec{a}$) respectively ($\vec{a}^T$):

$$\vec{a} = (a_{si}; a_{mi}; a_{di}; a_{ci}; a_{ri}) \qquad \Leftrightarrow \qquad \vec{a}^T = \begin{pmatrix} a_{si} \\ a_{mi} \\ a_{di} \\ a_{ci} \\ a_{ri} \end{pmatrix} \qquad \forall \qquad i = 1,\ldots,n) \in IN^{+}. \tag{5}$$

Thereafter the *total GHG emissions (e_{ki}) concerning a certain sub-process element* ($k = s, m, d, c, r$) can simply be calculated by multiplying the just identified number of needed CO_2

driver units (a_{ki}) by its associated value of caused GHGs due to the usage of a single CO_2 driver (u_{ki}) [3]:

$$e_{ki} = u_{ki} \bullet a_{ki} \qquad \forall \qquad k = s,m,d,c,r \wedge i = 1,\ldots,n) \in IN^{+}. \tag{6}$$

This intermediate stage is introduced in order to calculate CO_2 figures that can be used for benchmarking. If there e.g. appear the same sub-process elements within two corporations of the regarded SC and significant differences of CO_2 emissions set free can be assessed then it will be possible to identify the main reasons and introduce improvements. Thus the concept of a *continuous improvement process* (CIP) is embedded in the total CO_2 calculation model, too.

On the fifth stage a simple aggregation of all CO_2 emissions caused by those sub-process elements needed for revealing a certain product or service carbon footprint calculation occurs. As e.g. fast moving consumer goods are manufactured in large-scale batches the total amount of GHG emissions set free during the entire life-cycle of the corresponding product or service categories has to be measured or estimated by cumulating all process-related GHG emissions already quantified on the previous stage. At the end of stage 5 one consolidates all figures calculated with the aid of equitation (6) indicating the outcome as *total CO_2 amount per product or service category* ($E_{category}$). Another opportunity to directly calculate $E_{category}$ is multiplying vector ($\vec{u}$) (Stage 3) by vector ($\vec{a}^{T}$) (Stage 4). These considerations can mathematically be formulated as follows:

$$E_{category} = \sum e_{ki} = \vec{u} \bullet \vec{a}^{T} \qquad \forall \qquad k = s,m,d,c,r \wedge i = 1,\ldots,n) \in IN^{+}. \tag{7}$$

Lastly on stage 6 *total CO_2 emissions caused by a single product or service are provided*. The category related values calculated on the basis of equitation (7) have to be divided by the total amount of offered products or services (x). This ratio is *the carbon footprint* ($E_{product/service}$):

$$E_{product\,service} = \frac{E_{category}}{x} \qquad \forall \qquad x \in IN^{+}. \tag{8}$$

6. Conclusions

This paper highlighted the *rising importance of sustainable strategies within SCM*. As not only single corporations are faced with the needs of society, as e.g. environmental protection, *entire SCs* have to consider adequate actions – for instance installing SCSR. More often *customers deliberately integrate environmental belongings into their buying decisions*. This makes it occasionally necessary to present a *SC's contribution towards green thinking*, too. One specific tool to measure or estimate the impact of economic actions on global warming is the *product or service carbon footprint* extensively analysed. *As both in practice and theory just a few approaches of how to successfully calculate GHG emissions within SCs exist a six stage calculation model was proposed revealing the total CO_2 amount referred to single products or services*. In the course of a *literature research* concerning CO_2 calculation in SCM it became obvious that there is a number of articles already discussing the measurement of GHG emissions within *logistics* – for instance *CO_2 measurement in road* [15, 21] and *rail transportation* [6]. Only a few researchers included *manufacturing*, *consumer use* or *disposal into their considerations*. It seems that there is *lack of academic action linking CO_2 measurement of common SC processes and product or service carbon footprinting*. Thus future research has to be pursued within these fields. And finally the *proposed CO_2 calculation model has to be evaluated* by transferring it into practical use, i.e. applying to daily business actions.

7. References

1. Aronsson, H., Brodin, M.H., Kohn, C., 2008. Logistics Structures – Drivers of Environmental Impact. In: Arlbjørn, J.S., Halldórsson, Á., Jahre, M., Spens, K. (Eds.). *Northern Lights in Logistics & Supply Chain Management*. Gyllling: Narayana Press / Copenhagen Business School Press, 183-198.
2. Beamon, B.M., 1999. Designing the green supply chain. *Logistics Information Management*, 12 (4), 332-342.
3. BSI British Standards, 2008. *Guide to PAS 2050 – How to assess the carbon footprint of goods and services*. London.
4. Defee, C.C., Esper, T., Mollenkopf, D., 2009. Leveraging closed-loop orientation and leadership for environmental sustainability. *Supply Chain Management: An International Journal*, 14 (2), 87-98.
5. Delay, T., 2007. Carbon footprints in the supply chain: The next step for business? In: Sustainable Development International (Ed.). *Climate Action*. London: Westerham Press, 95-97.
6. Eickmann, C., 2002. Ermittlung der CO_2-Emissionen – Methoden zum Vergleich im Straßen- und Schienenverkehr. *EI – Der Eisenbahningenieur*, 53 (9), 116-122.
7. European Commission, 2007. *CARBON FOOTPRINT – what it is and how to measure it*. Ispra (VA), Italy, 1-2.
8. Fiksel, J., 2009. *Design for Environment – A Guide to Sustainable Product Development*. New York, Chicago, San Francisco, Lisbon, London, Madrid, Mexico City, Milan, New Delhi, San Juan, Seoul, Singapore, Sydney, Toronto: McGraw-Hill.
9. Franck, A., 2008. Sustainable Supply Chain Management – A tool for reinforcing shareholder value. In: Accenture (Ed.). *Supply Chain Management Viewpoint*. Hamburg.
10. Halldórsson, Á, Kotzab, H., Skjøtt-Larsen, T., 2009. Supply chain management on the crossroad to sustainability: a blessing or a curse? *Logistics Research*, 1 (2), 83-94.
11. Handfield, R.B., Nichols, E.L., 2002. *Supply Chain Redesign – Transforming Supply Chains into Integrated Value Systems*. Upper Saddle River: Financial Times Prentice Hall – an imprint of Pearson Education.
12. Haubach, C., Schmidt, M., 2008. Erweiterung der Systemgrenzen betrieblicher Umweltinformationssysteme – Integration der Supply Chain am Beispiel der „CO_2-Rechner“. In: Hegering, H.-G., Lehmann, A., Ohlbach, H.J., Scheideler, C. (Eds.). *INFORMATIK 2008 – Beherrschbare Systeme – dank Informatik*, Bd. 2, Lecture Notes in Informatics 134. Bonn: Gesellschaft für Informatik, 867-872.
13. Hegmann, G., 2009. Neue Logo-Farbe – McDonald's wechselt von Rot auf Grün. München: *Financial Times Deutschland*, 23.11.2009.
14. Hutchins, M.J., Sutherland, J.W., 2008. An exploration of measures of social sustainability and their application to supply chain decisions. *Journal of Cleaner Production*, 16 (15), 1688-1698.
15. Kranke, A., 2009. CO2-Berechnung. *Logistik inside*, 8 (5), 47-49.
16. Lamming, R.L., Hampson, J., 2008. The Environment as a Supply Chain Issue. In: New, S. (Ed.). *Supply Chain Management – Critical Perspectives on Business and Management*, Vol. IV – Ethics, Environment and Social Impacts. London, New York: Routledge – Taylor & Francis Group, 161-190.
17. Lamsali, H., 2006. Performance Measurement of Green Supply Chain Management (PM/GSCM). In: Blecker, T., Kersten, W. (Eds.). *Complexity Management in Supply Chains – Concepts, Tools and Methods*. Berlin: Erich Schmidt Verlag, 303-311.
18. Liebrich, S., 2009. Öko-Strategie von McDonald's – Grün allein genügt nicht. München: *Süddeutsche Zeitung*, 24.11.2009.
19. Mangan, J., Lalwani, C., Butcher, T., 2008. *Global Logistics and Supply Chain Management*. Chichester: John Wiley & Sons.
20. Marsmann, M., 2000. The ISO 14040 Family. *The International Journal of Life Cycle Assessment*, 5 (6), 317-318.

21. McKinnon, A.C., Piecyk, M.I., 2009. Measurement of CO_2 emissions from road freight transport: A review of UK experience. *Energy Policy*, 37 (10), 3733-3742.
22. Middendorf, K., 2008. Logistik im Spannungsfeld zwischen Globalisierung und Nachhaltigkeit. In: Baumgarten, H. (Ed.). *Das beste der Logistik – Innovationen, Strategien, Umsetzungen*. Berlin, Heidelberg: Springer-Verlag, 405-413.
23. Palupski, R., 2003. *Über Führung – Lern- und Denkbuch*. Essen: MA Akademie.
24. Poluha, R.G., 2007. *Anwendung des SCOR-Modells zur Analyse der Supply Chain – Explorative empirische Untersuchung von Unternehmen aus Europa, Nordamerika und Asein*. Dissertation. In: Seibt, D., Kemper, H.-G., Herzwurm, G., Stelzer, D., Schoder, D. (Eds.). Wirtschaftsinformatik, Bd. 50. Lohmar, Köln: Josef Eul Verlag.
25. Rodrigue, J.-P., Slack, B., Comtois, C., 2001. Green Logistics. In: Brewer, A.M., Button, K.J., Hensher, D.A. (Eds.). *Handbook of Logistics and Supply-Chain Management*. In: Hensher, D.A., Button, K.J. (Series Eds.). Handbooks in Transport 2. Amsterdam, London, New York, Oxford, Paris, Shannon, Tokyo: Pergamon.
26. Schmidt, M., 2009. Carbon accounting and carbon footprint – more than just diced results? *International Journal of Climate Change Strategies and Management*, 1 (1), 19-30.
27. Seebauer, P., 2008. Supply Chain unter der Öko-Lupe. *LOGISTIK HEUTE*, 30 (10), 54-55.
28. Sehgal, V., 2009. *Enterprise Supply Chain Management – Integrating Best-in-Class Processes*. Hoboken, New Jersey: John Wiley & Sons.
29. Sen, S., 2009. Linking Green Supply Chain Management and Shareholder Value Creation. *The IUP Journal of Supply Chain Management*, 6 (3 & 4), 95-109.
30. Sommer, P., 2007. *Umweltfokussiertes Supply Chain Management*. Dissertation, Internationales Hochschulinstitut (IHI) Zittau. In: Kramer, M. (Ed.). Studien zum internationalen Innovationsmanagement. Wiesbaden: Deutscher Universitäts-Verlag.
31. Supply-Chain Council, 2005. *Supply-Chain Operations Reference-model – SCOR Version 7.0 Overview*. Washington DC, Brussels.
32. United Nations Framework Convention on Climate Change, 1998. *Kyoto Protocol to the United Nations Framework Convention on Climate Change*.
33. United Nations Framework Convention on Climate Change, 2009. *Copenhagen Accord*.
34. Wackernagel, M., Rees, W., 1996. *Unser ökologischer Fußabdruck – Wie der Mensch Einfluß auf die Umwelt nimmt.* Basel, Boston, Berlin: Birkhäuser Verlag.
35. Wiedmann, T., Lenzen, M., 2008. Unravelling the Impacts of Supply Chains – A New Triple-Bottom-Line Accounting Approach and Software Tool. In: Schaltegger, S., Bennett, M., Burritt, R.L., Jasch, C. (Eds.). *Environmental Management Accounting for Cleaner Production*. In: Tukker., A. (Series Ed.). Eco-Efficiency in Industry and Science, 24. o.O: Springer Science + Business Media B.V., 65-90.
36. Wiedmann, T., Minx, J., 2007. A Definition of 'Carbon Footprint'. In: Pertsova, C.C. (Ed.). *Ecological Economics Research Trends*. New York: Nova Science Publishers, 1-11.
37. Winkler, H., Kaluza, B., Schemitsch, H.B., 2006. *Managing economical and ecological goal conflicts – demonstrated in the context of Sustainable Supply Chain Networks*. Discussion Paper of the Economic Sciences at the Alpen-Adria-Universität Klagenfurt.
38. Wittneben, B.B.F., Kiyar, D., 2009. Climate change basics for managers. *Management Decision*, 47 (7), 1122-1132.
39. World Business Council for Sustainable Development, 1998. *Corporate Social Responsibility Stakeholder Dialogue, 6-8 September 2008*. Noordwijkerhout, The Netherlands.
40. World Business Council for Sustainable Development, World Resources Institute, 2004. *The Greenhouse Gas Protocol – A Corporate Accounting and Reporting Standard*. Washington, DC: World Resources Institute.
41. World Commission on Environment and Development, 1987. *Our Common Future*. Oxford, New York: Oxford University Press.