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Carbon accounting for sustainability and management. Status quo and challenges

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ABSTRACT

This paper provides an overview of carbon accounting as a rapidly developing area of sustainability management and this special issue. The global nature of greenhouse gas emissions as well as increasing climate change impacts is a context that demands new, more holistic approaches to preventing and reducing the negative impacts of climate change. This requires improved ways to anticipate and to fulfil new information requirements and to provide guidance on how to use the evolving accounting approaches for transparency, accountability and decision-making in governments, companies, academia and in non-profit organizations. Different types of carbon accounts – scientific, political, economic and corporate, are evolving. They are related but are not properly interlinked in policy or strategic. On the corporate level, carbon accounting can support carbon management with two basic approaches, *carbon accounts for un-sustainability* and *carbon accounting for sustainability improvements*. Both approaches play an increasing role for corporate functions such as production, distribution, procurement, supply chain management, innovation, communication, and marketing. Carbon management accounting can support all organizational levels in decision-making, regardless of whether a department is particularly challenged to comply with regulations, to better organize energy and material flows for substantial reduction effects, or is motivated to increase eco-efficiency, product innovation or legitimacy. This paper distinguishes different company-internal areas of application and methods of carbon accounting. To support corporate decision-makers environmental management accounting framework provides a structured overview of methods distinguishing physical and monetary approaches to carbon accounting. With the expanding scope of carbon accounting practices to include supply chains and product life-cycles, researchers are challenged to develop new methods, such as input–output assisted hybrid accounting.

1. Introduction

1.1. Introduction to this special issue and to this paper

This special issue provides new insights on climate accounting and discusses carbon management accounting issues and methods in theory and practice. Günther and Stechemesser present the first systematic literature review on carbon accounting on different levels. If researchers wish to contribute to combatting climate change they have to go beyond publications, which only inform. This is why Burritt and Tingey-Holyoak highlight the importance of establishing effective linkages between academia and industrial practice to more effectively address climate change issues dynamically. In line with this, Ascui and Lovell analyse how professional accounting bodies strengthen their carbon accounting competences. Sullivan and Gouldson examine whether voluntary carbon reporting meets investors' needs, a requirement, which has to be met if accounting and reporting are to effectively influence investor decisions. Pellegrino and Lodhia investigated the expected effects of carbon reporting in the mining industry and whether corporate disclosure can or does create legitimacy.

In order to create real improvements in carbon reductions, carbon accounting must support managers to take the 'right' decisions. Lee explores this perspective for supply chain management in the automobile industry. Areas of decision-support with carbon accounting are addressed by Scipioni et al. who propose a methodology for more effective monitoring the carbon footprint of products. In support of that approach, Tsai et al., report on how 'activity-based costing' can help companies to integrate carbon cost information into their accounting and management.

This paper provides an overview of the area of carbon accounting and an introduction to this special issue by discussing how different levels of carbon accounting relate to each other

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(Section 2), what functions corporate carbon accounting can fulfil and what methods exist (Section 3), and by concluding with an overview of future directions of carbon accounting to support corporate sustainability management.

1.2. Contextualizing sustainable development, climate change and carbon accounting

This section positions carbon accounting in the context of climate change and sustainable development. Climate change is considered to be one of the six major sustainability problems (among deforestation, loss of biodiversity, population growth, poverty, scarcity of drinking water, climate change), and possibly it is the fundamental one (e.g. IPCC, 2007; Stern, 2007). Both, the main causes and the impacts of climate change are directly linked to economic and social activities. For example uses of fossil fuels for generating electrical power (41%), transport (23%) and industrial uses (20%) are among the main causes for carbon dioxide emissions in the world (IEA, 2011). Examples of large impacts include the ecological effects of melting glaciers in mountains, Arctic and Antarctic regions or the social and economic consequences of rising sea levels in densely populated areas such as in Bangladesh, the Netherlands and large parts of the Asia Pacific region. Scientific climate change evidence includes data on the increasing frequency and severity of weather events, including droughts, fires, typhoons and hurricanes. Combatting climate change is an urgent topic of sustainable development (Banuri, 2009).

Notwithstanding these assessments, scientific researchers have concluded that the global 'carbon bottom line' is still increasing and putting eco-systems, the global society and the existing economies at a historically, incomparably high risk. In contradiction to the necessity for carbon emission reductions, the overall greenhouse gas releases have increased world-wide for the last decade, largely due to the rapid growth of large emerging economies such as China and India, while other large economies such the United States have not been sufficiently willing to reduce their already exceedingly high emission levels. In spite of the relative ineffectivity of international efforts, some national strategies are making progress (on national developments see e.g. Karlsson et al., 2011; Hovi et al., 2010). Few countries with very high greenhouse gas emission levels such as Germany and the Netherlands are leading the reduction efforts (see IEA, 2011), whereas, vulnerable nations such as the nations in the 'Coalition of Pacific Island States' are urging the international community to become actively involved in climate change prevention and adaptation efforts. Others, like Australia or China, are observing and following other's lead in efforts to reduce per capita carbon emissions.

For the last two decades Europe has been successful in partially decoupling greenhouse gas (GHG) emissions from GDP growth (Fig. 1). Starting from a high GDP level, a substantial real GDP growth of 30% for the EU15 countries (in average 1.7% per annum) was achieved between 1995 and 2010 while the GHG emissions decreased by more than 10 per cent during this time.

At first the data presented in Fig. 1 suggest that climate policy is doing well in Europe, and is setting an example for other parts of the world. Other regions and large economies kept increasing their carbon dioxide (CO_2) emissions; China releasing a major part of the global of greenhouse gas emissions for the last two decades (Fig. 2).

The European achievement in curbing carbon emissions in spite of economic growth, however, is only partly a 'real' improvement in efficiency and emission reductions. Much of the apparent reductions of carbon emissions are due to the fact that they were 'exported' with major shifts of industrial production to Asia. Weber et al. (2008) documented that in 2005 approximately 30% of Chinese emissions were related to the production of exports and that this share increased rapidly in the early 2000's. Furthermore, substantial differences in emissions exist among different industrial sectors. Although the manufacturing sector in Europe has reduced its climate impact over the last twenty years, the transport sector has caused a rapid growth of emissions for the same period

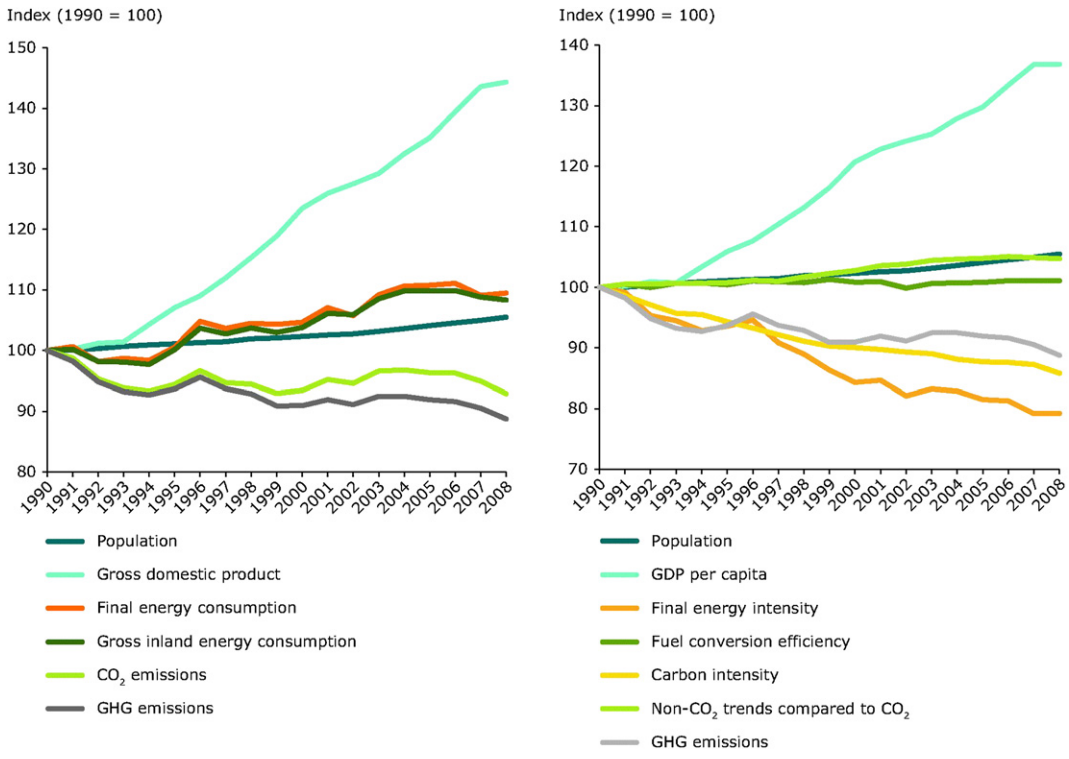


Fig. 1. GHG emissions and GDP growth appear to be decoupled within the European Union (source: EEA, 2010, p. 20).

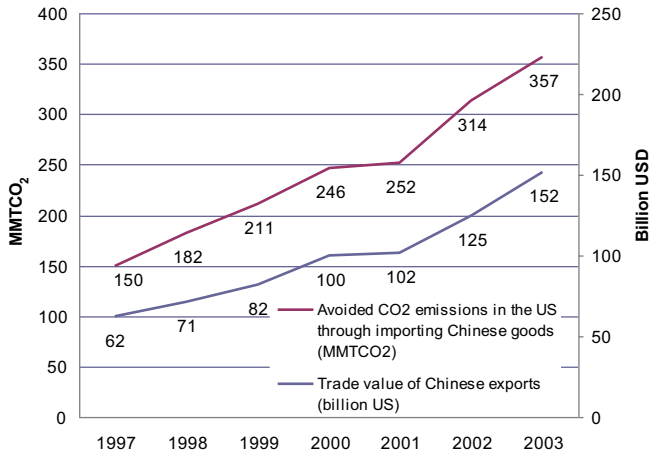


Fig. 2. The evolution of CO_2-emissions differs among nations during the time horizon, 1990–2007 (source: WRI, 2011).

(IEA, 2011). This indicates that globalization is causing major shifts in carbon emissions from industry to transportation. Commercial and private transportation continue to increase and much economic value is wasted due to increasing congestion and millions of hour spent traffic jams.

Fig. 3 shows a similar development in the USA where carbon emissions have been exported with the shift of industrial production to Asia, however with the difference, that the USA has increased its domestic CO_2 emissions. Weber and Matthews (2007) created a multi-country input–output model for estimating embodied carbon emissions and forecasted that if this trend continues, emissions embodied in US imports will exceed emissions of domestic production within 20 years.

Thus, a large and increasing share of European and US GHG emissions are embedded in imported goods as a 'carbon rucksack' (see e.g. von Weizsäcker et al., 1997; Weizsäcker et al., 2009). Moreover, the CO_2 intensity of products has often increased, partially as a result of more transportation for longer distances. National carbon accounts, both in developed and in developing countries, are therefore, distorted with regard to who actually causes the carbon emissions and has the related responsibilities (e.g. Bastianoni et al., 2004).

The large and increasing share of GHG emissions 'hidden' in imported goods underlines the importance of calculating the carbon emissions and impacts of supply chains and product life cycles, including the emissions caused by semi-manufactured products imported by manufacturing industries. Growing complexity and flexibility of supply chains, however, poses substantial challenges to this kind of carbon accounting.

Given that energy systems, product designs, and production processes of all kinds are major direct and indirect sources of carbon emissions, companies are especially responsible for reducing the life cycle emissions of their products and services, globally. Greenhouse gases are different from local pollution in terms of technological control possibilities. End-of-pipe technologies, for example, electrostatic precipitators, scrubbers, carbon capture and storage, etc., are not technically or economically viable options to curb greenhouse gas emissions (e.g. Gibbins and Chalmers, 2008).

The current emphasis of greenhouse gas reduction indicators is on improvements in process efficiency and efficient consumer products. This is an important area of activity, however, the strong global population growth and the economic growth, particularly in large developing countries, currently out-weighs the efficiency improvements. Carbon accounting is therefore challenged to support radical reductions of total carbon impacts exceeding efficiency improvements.

More encompassing approaches such as consumer, product and supply chain related accounting methods, e.g. accounting for carbon labelling of products and life cycle costing are under development, but are not yet useful in practice. Policies aiming at controlling industrial processes have been complemented by product-oriented indicators in the EU environmental policy. "Up to now, product-related environmental policies have tended to focus on large point sources of pollution, such as industrial emissions or waste management issues. Now, however, it is becoming clear that they need to be complemented by a policy that addresses the whole product's life cycle, including the use phase. This should ensure that environmental impacts throughout the life-cycle are addressed in an integrated way – and so are not just shifted from one part of the life-cycle to another" (EC, 2003, p. 3, 2007).

Efforts to combat climate change will fail if companies are not successfully engaged in reducing carbon emissions from their entire product-service systems. International and political institutions have introduced different measures with varying (lack of) rigidity and scope (Garnaut, 2010). In many countries corporations are being held accountable for their carbon impacts through various forms of environmental legislation. Regulatory and political pressures, such as the Kyoto protocol, emissions trading in the EU and carbon taxes in Australia (e.g. Pellegrino and Lodhia, 2012), are sometimes accompanied by public policies that support

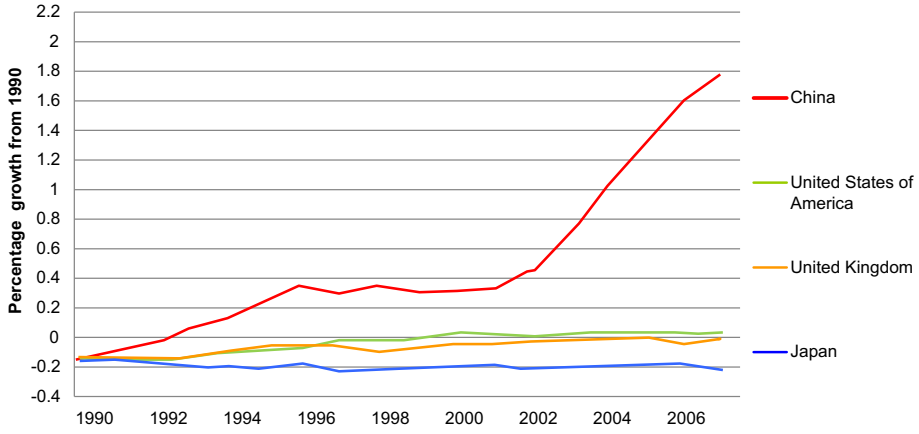


Fig. 3. The avoidance of CO_2 emissions within the US parallels the increases in Chinese exports to the US during the period 1997–2003. (Shui and Harriss, 2006, p. 4066.)

shifts to biofuels, to other forms of renewable energies and to improved societal energy efficiency. The international and national carbon policies are being complemented with international standards with a particular focus on different kinds of corporate carbon accounting. Standards, such as the British Standard PAS 2050 for carbon labelling, ISO 14067 for carbon footprinting of products, or ISO 14064 for GHG reporting, are responses to industry's need for generally acceptable methods of physical carbon management accounting.

Voluntary corporate initiatives also play an important role in creating change. The management of GHG emissions is now on the agenda of top management of leading companies and advanced business associations (e.g. Carbon Disclosure Project; 2-degree initiative see: http://www.initiative2grad.de/). Carbon management and accounting divisions have been developed in major consulting companies and professional accounting organizations are defining their approaches to carbon accounting (e.g. Ascui and Lovell, 2012; Ratnatunga and Balachandran, 2009).

This means that carbon management is emerging as a new, far reaching, interdepartmental management function designed to assist in achieving substantial carbon reductions in companies, institutions and homes. Corporate carbon management requires them to not only comply with regulations and to react on societal pressures and market changes or to create arrangements of self-regulation (e.g. Andrews and Cortese, 2011), but to pro-actively incorporate carbon-related issues into their business models, strategies and practices (e.g. Schaltegger et al., 2012; Unerman and O'Dwyer, 2007). Management is challenged to organize a structural and strategic change of corporate institutions and supply chains (e.g. Lee, 2012). As with most major management decisions, a good information system is also crucial to design and support these changes to incorporate greenhouse gas considerations into mainstream business activities. Given that accounting conventionally provides the main management information systems in a company, carbon management accounting can increasingly become a crucial tool for combatting climate change.

This paper proceeds as follows: Section 2 describes a framework linking different levels of carbon accounting. The third section discusses corporate carbon accounting in more depth and highlights the necessity to overcome the existing dichotomy between critical accounting for un-sustainability and the pragmatic accounting for sustainability improvements. The paper concludes in Section 4 with an outlook for future research.

2. The role of accounting in combating climate change

2.1. Levels and purposes of carbon accounts

Carbon accounting is relevant at different institutional and geographical levels. Fig. 4, displaying a framework for carbon accounting, shows that climate change issues are addressed on scientific, political-economic and corporate levels as well as on global/multinational, national and local levels. Multinational, national and local scientific carbon accounts relate climate change data to political levels and economic development. These accounts can provide reference points and orientation for corporate carbon accounting.

Accurately developed greenhouse gas accounts document the extent of the effects and problems, help to create awareness and provide reference points for the types and extent of emissions that must be reduced to begin to make progress toward more sustainable societies. By translating the ecological information into economic terms and into more or less specific policy goals, the political and economic accounts can provide orientation to companies.

Companies can take account of their climate change impacts (i.e. of the 'bad' effects contributing to un-sustainability), which provide

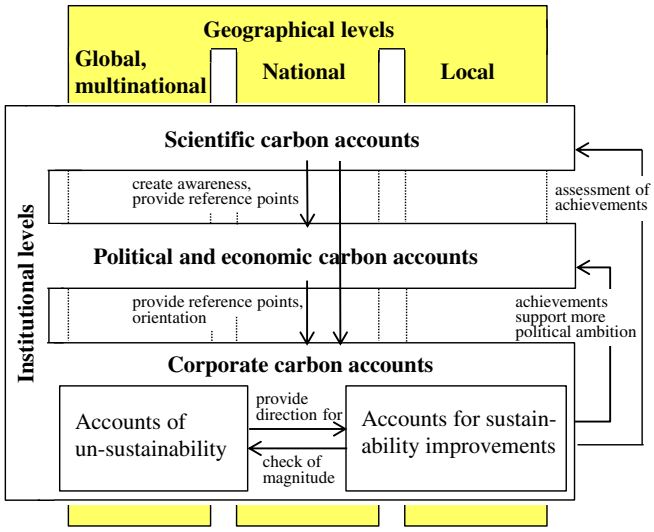


Fig. 4. Information from different levels of carbon accounts can be used to improve the quality of decision-making at all levels.

direction for improvement measures and for planning, implementing and accounting for how effective their mitigation measures are. The interplay of corporate accounts for un-sustainability and accounts for sustainability improvements can support organizational learning processes. Depending on the scope and size of the company and its supply chains, corporate accounts can be multinational, national or rather locally focused. Corporate accounting and reporting information can be used on political and scientific levels to assess whether the achievements are sufficient or not and to develop more political commitment where it is needed. Quantified accounts of what has been achieved help corporate managers to compare the magnitude (or lack) of improvements with what is needed to effectively combat climate change.

Ideally, political and corporate actions should be based upon scientific knowledge so that information about carbon account dynamics, at all levels, provides decision-makers insights into cybernetic feedback loops that must be worked with for improving their climate change decisions and actions at all levels. As part of this process, graphic displays of the increasing levels of CO_2 concentrations in the atmosphere, the increases of global temperatures, etc. are raising awareness of the general public, media and policy-makers (Table 1).

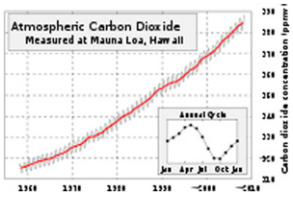
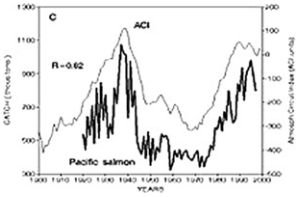
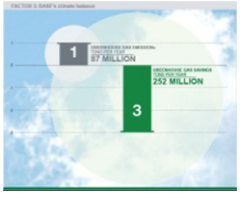
Political and economic carbon accounts relate natural scientific information with economic consequences and frequently help to foster political action. Examples of such accounts are the influence of climate change on fish catch, or the costs of climate change related floods on infrastructure.

On the corporate level, companies issue carbon information to various stakeholders such as media, NGOs, regulators or customers to inform about their achievements or influence consumer choices for 'carbon reduced' or 'carbon neutral' products. Although some corporate carbon accounts relate to economic and scientific accounts (e.g. MunichRe, 2010; SwissRe, 2011) they are mostly focused on tracking the current level of carbon emissions and developments over time.

2.2. Scientific carbon accounts

Information about the phenomenon of climate change and its ecosystems relevance is largely scientific and often presented in terms of physical measures of carbon dioxide concentration and

Table 1
Different institutional levels address different actors, purposes and types of information.

Institutional levels of account	Providers	Main addressees	Purposes	Types of information	Examples
Scientific	Academia, international organizations	General public, media, politicians, academia	Raise awareness	Physical, quantitative, ecological	Keeling curve displaying increasing carbon dioxide levels 
Political and economic	International organizations, academia	Politicians, industry associations	Urge action	Monetary, physical, quantitative	Variation of Pacific salmon catch and correlation with a climate-related Atmospheric Circulation Index 
Corporate	Companies	Stakeholders	Inform about achievements and influence choices	Physical, monetary, quantitative, qualitative	BASF (2008) reporting its carbon balance 

temperature increases, effects on the thickness of glaciers, biodiversity loss, changing marine ecosystems, etc. (for examples see e.g. IPPC, 2007). These accounts build the foundation for all scientific work related to climate change effects and the justification for political and corporate climate policies. This also includes evolving policies relating to renewable energies, biofuel policies, energy efficiency and to, directives on carbon emissions for cars or incentives for increasing use of biomass in industry.

The most famous scientific carbon account is the 'Keeling Curve', a graph which shows the long-term increase of atmospheric CO_2 concentrations for the fifty year period from 1958 to 2008. Monthly CO_2 measurements display seasonal oscillations in an upward trend; each year's maximum occurs during the Northern hemisphere's late spring, and it declines during the growing season when the plants utilize atmospheric CO_2.

It has to be kept in mind, that CO_2 is a major, but not the only emission, which contributes to climate change (other GHG emissions include methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), per fluorinated compounds (PFCs) and hydro fluorocarbons (HFCs)). Therefore, the relevant indicator to measure the impact of emissions on climate change is CO_2-equivalents (e.g. Heijungs et al., 1992; IPCC, 2007; Schnellnhuber et al., 2006).

Because of this, climate change accounting should not only include CO_2-emissions but all greenhouse emissions (including CH_4, N_2O, etc.) and should consider them according to their relative global warming potential as CO_2-equivalents (e.g. IPCC, 2007; Heijungs et al., 1992).

To avoid confusion, the concept of 'greenhouse gas accounting' could be used for accounts, which include all greenhouse gases and 'carbon accounting' if only carbon dioxide emissions are being addressed. However, the current literature provides a mixed picture of the use of terms and a variety of scopes (see Günther and Stechemesser, 2012). One reason for this may be that climate impacts of different greenhouse gases are often expressed in carbon dioxide equivalents. Thus 'carbon accounting' seems to have developed as a general umbrella approach that covers all forms of greenhouse gas and carbon accounting.

2.3. Political and economic carbon accounts

Political and economic accounts of climate change (for examples of the effect of global warming scenarios on fish stocks) translate the scientific information into physical and monetary economic figures and politically relevant scenarios but remain on the macro level. These accounts have been influential in defining target goals for CO_2 emissions and reductions in international conferences such as the Kyoto- and in follow-up conferences on global warming (Peters and Hertwich, 2008). They have also been used for developing support for national carbon policies (e.g. Minnesma, 2003 for the Netherlands), programmes and for guidance papers developed by industry associations (e.g. Baily, 2007 or the Pew Center for Climate Change, 2010). A common target which has been defined and referred to by a wide array of organizations, including many companies, is to limit the increase of global average temperature to

2 °C by reducing greenhouse gas emissions to the level of 1990 (EC, 2007; or http://www.initiative2grad.de/).

These macro carbon accounts and the derived goals of reducing carbon emissions by stabilizing average concentrations and temperatures frequently serve as reference points for corporate carbon goals, strategies, measures and reporting (e.g. Xerox's energy challenge program, or the zero carbon target for the builders of new dwellings in UK by 2016; Osmani and O'Reilly, 2009) The operationalization of these goals through corporate policies requires carbon accounting on the company level.

Although some professional accounting associations (e.g. ACCA, 2011; CIMA, 2010; FEE, 2002; ICAEW, 2003, 2004) have produced supportive reports, which address carbon accounting issues, the traditional accounting standardization organizations such as the International Accounting Standards Board (IASB) or the US Financial Accounting Standards Board (FASB) have so far not seriously dealt with the topic. In order to begin to fill this vacuum, the lead in the standardization of carbon accounting has been taken by the Carbon Disclosure Standards Board (CDSB, 2010). Currently, the major international standard which links international initiatives on climate change, political goals with the corporate level and carbon management accounting is the Greenhouse Gas (GHG) Protocol developed by the World Resources Institute and the World Business Council for Sustainable Development (GHG Protocol, 2011a, 2004). Further influence on standardization of corporate carbon accounting can be expected from the British Standards Institute which has issued PAS 2050, and the International Institute for Standardization (ISO) which is preparing its own carbon accounting standard ISO 14067.

2.4. Corporate carbon accounting of growing business relevance

Corporate practice in relation to collecting, managing and communicating corporate carbon related information is still under-researched (e.g. Hopwood, 2009; Kolk et al., 2008; Lohmann, 2009; Milne and Grubnic, 2011) particularly with regard to corporate practice (see e.g. Burritt et al., 2011b). Carbon related information is, however, not only of major ecological but also of growing economic and business relevance due to regulatory, societal and market influences.

From the regulatory side, greenhouse gas information has received increasing attention through the introduction of emission trading systems (e.g. in the European Union), carbon limits (e.g. for new cars in the EU) and carbon tax (e.g. in Australia), the Cleaner Development Mechanism and Joint Implementation measures (e.g. ECOMAC, 1996; Kossoy and Ambrosi, 2010; Lohmann, 2009; Milne and Grubnic, 2011; Ratnatunga, 2008). The business relevance of these regulations is most apparent for airlines. Lufthansa, the second biggest European airline, estimated costs of 130 million Euros per year for the EU ETS system (Der Spiegel, 2012) and threatened to relocate its hub operations from the European Union to Switzerland which is outside the EU jurisdiction. The option of creating 'pollution havens' underlines the importance of coordinated public GHG policies and international carbon accounting rules. A substantial step in this direction has been made with the Greenhouse Gas Protocol which defined three scopes and accounting rules for corporate carbon accounting (e.g. GHG Protocol, 2004, 2011a,b,c).

Societal pressure, expressed in media reports, NPO communication or published targets established by business associations and investor groups such as the Carbon Disclosure Project and the Carbon Disclosure Standards Board (see CDP, 2011; CDSB, 2010) reflect increasing public and stakeholder awareness in many countries and industries, worldwide world (e.g. PWC and CDP, 2010). As a result, information on carbon emissions is included in a variety of reports, websites and media. Some of the reported carbon information is subject to standardized quantitative measures and in some cases also audits or verification processes have been done (e.g. Bebbington and Larinaga-González, 2008). The International Organisation of Standardisation issued its ISO 14064-1:2006 standard that specified principles and requirements for the organizational level for quantification and reporting of greenhouse gas emissions and removals. It includes requirements for the design, development, management, reporting and verification of an organization's GHG inventory.

Various markets have taken up carbon topics such as the financial investor market (e.g. CDP, 2011; KPMG, 2008; see also Sullivan and Gouldson, 2012) for sustainably responsible investments and to a growing degree, also as part of mainstream financial and sustainability assessments (e.g. Hopwood, 2009; Milne and Grubnic, 2011). In this context the corporate value relevance of carbon emission allowances (e.g. Johnston et al., 2008) and taxes is increasingly discussed among financial analysts and investors. In various goods and service markets such as electricity generation, food, outdoor clothing and automotives (Silitonga et al., 2012), carbon footprint labels (e.g. Carbon Trust, 2006; Holliday, 2010) or information on carbon emissions, carbon reductions or carbon neutrality have become part of consumer communication. Carbon related research and new markets have emerged and are being fostered by sustainable entrepreneurs who are offering climate reduction management consulting, climate offsetting services (see e.g. the Plan Vivo project in Mexico (Corbera et al., 2009; Dhanda and Hartman, 2011), carbon footprint services (Murray and Dey, 2009) or advise designed to help their clients to lower their carbon emissions through carbon neutral products and services. Dole, for example, is working to implement a carbon neutral product supply chain for bananas and pineapples from their production sites in Costa Rica to the US and European markets. Their work includes efficiency improvements in transportation and agricultural practices and offsetting in terms of reforestation programs (Kilian and Jiménez, 2011).

However, these emerging markets need improved accounting methods, procedures and standards. Dhanda and Hartman (2011) studied 117 carbon-offset providers and found the market highly unregulated and the available standards to be inconsistent. To increase the credibility, reliability and comparability of carbon offsets accounting, monitoring, verification and certification standards as well as auditing and registration standards are urgently needed.

With regard to accounting systems and tools, corporate carbon accounting may be the most widely recognized application of sustainability accounting, being a pragmatic goal oriented approach to provide useful information to different managers in their decision making (Schaltegger and Burritt, 2010). This information can have an internal or external focus and corporate carbon accounting as an information system is linked to corporate strategy (e.g. Kolk and Pinske, 2005, 2008) as well as to specific outcomes in relation to corporate sustainability (for an overview on corporate sustainability see e.g. van Marrevijk, 2003; Schaltegger and Burritt, 2005).

Reviewing the interplay between these levels of carbon accounting is neither necessary nor sufficient to explicitly relate corporate carbon accounts to macro-level measures of the global phenomenon of un-sustainability but for all who work to solve the environmental threats to global sustainability it is essential to establish carbon accounting and management systems, which enable managers to substantially improve the operational carbon performance in environmental and economic terms. This is why pragmatic carbon management accounting focuses on supporting managers in creating real improvements without neglecting business realities and goals.

In summary, carbon information management and accounting are becoming economically relevant topics for corporate management (e.g. WRI, 2011). In this context the GHG Protocol has developed three scopes of carbon accounting, which are discussed in Section 3.

3. Carbon accounting for carbon management

3.1. Functions of corporate carbon accounting

Carbon management accounting can be described as that part of carbon accounting, which supports companies in the successful operationalization and implementation of their carbon management. As a means for identifying, collecting, processing, disclosing and communicating carbon information, carbon management accounting encompasses a set of information management tools which are commonly used as part of carbon management and carbon policy in private and public organizations.

Various tools of environmental management accounting have been developed and applied (see e.g. Burritt et al., 2011b; Schaltegger and Burritt, 2000; Unerman et al., 2010), however, only a limited amount of research has been conducted on the practical implementation and use of carbon management accounting (e.g. Bennett et al., 2003; Burritt et al., 2011b; PWC, 2010; Okereke, 2007; Jeswani et al., 2007; Hoffmann and Busch, 2008; Schaltegger et al., 2008).

Key non-explored or hardly explored issues of carbon management accounting include the design of processes, measures and indicators to document all carbon emissions of a supply chain, to clearly identify and allocate carbon emissions to production processes, products and activities or to secure high quality information including auditing and assurance. The GHG Protocol (2011a,b) provides many useful rules and is an important standard but it must be further developed to be more helpful in corporate practice. Little is known about the information that is needed to provide good decision-making support. Additionally, little is known about why and how often companies do or should collect carbon information and how this information is or should be used to facilitate implementation of improvements.

Therefore, sustainability accounting researchers should increase their efforts to understand corporate challenges of carbon accounting, auditing and assurance practices and to provide support for further institutionalization and dissemination. This includes a differentiated support of all corporate functions, with activities like:

- *Creating transparency and to take account of un-sustainability of the past and current operations:* What were and are the carbon impacts of the production processes, products and supply chains? How substantial are these emissions compared to those that are scientifically and politically defined, or to their own carbon reduction goals, the goals and achievements of competitors, etc.? Which sources and drivers cause these carbon emissions? Related to the carbon emissions, what are or will be the costs of these carbon impacts (internally and externally)?
- *Forecasting future greenhouse gas emissions*: What carbon impacts can be expected in the future, if operations continue and business plans are achieved? How does this forecast relate to the politically defined and the corporate goals? What will or could be the main sources and drivers of carbon impacts in the future? What costs will this cause (internally and externally)?
- *Identification of reduction potentials and evaluation of reduction measures*: What alternative, less carbon intensive ways of production, sourcing, and product design, etc. exist or need to be developed and implemented? What would the carbon impacts and reductions of these alternative ways of production and organization, alternative products and business models, etc. be for the company? What costs, revenues and profitability trends would be related to implementation of these alternatives?
- *Support of the implementation of carbon management measures:* What operational measures are needed, and what further environmental and economic costs and benefit results will introduction of more carbon friendly processes, products, and business models deliver? Have the implemented measures successfully reduced the climate impacts and if not why not, and what correction activities are needed?

The first two sets of activities focus on unveiling the undesired bad effects and problems and are designed to help them develop a corporate carbon account of un-sustainability (Table 2). They should strive for creating transparency about past impacts and to forecast future greenhouse gas emissions. This mostly static or comparative kind of accounting is a necessary basis to create transparency and awareness but must be complemented by dynamic and enabling accounting procedures in order to play useful roles in corporate carbon reduction management.

The enabling function of carbon accounting is supported by the pragmatic activities of identifying reduction potentials, evaluating measures and supporting implementation (for the enabling role of accounting, see Ahrens and Chapman, 2004). The basic roles of accounting, creating transparency and supporting improvement, are interrelated as described in Table 2.

The first group of accounting functions on creating transparency has been emphasized by the critical perspective of social accounting (e.g. Gray, 2010). The second group of functions has been emphasized by pragmatic sustainability accounting research (e.g. Burritt and Schaltegger, 2010; Schaltegger and Burritt, 2010)

Table 2
Carbon management accounting tools for documenting options for transitioning from un-sustainable to more sustainable corporate functioning have different characteristics and functions.

	Carbon accounting of un-sustainability	Carbon accounting for sustainability improvements
Core functions of carbon management accounting	• Creating transparency about past and current operations • Forecasting future impacts	• Identification of reduction potentials • Evaluation of reduction measures • Support of the implementation of reduction measures
Kind of prevailing accounting information		
• Physical or monetary	• Physical	• Physical and monetary
• Time frame	• Past oriented (mostly), little future oriented information	• Present and future oriented (mostly), little past oriented information
• Frequency of information	• Continuously generated	• Ad hoc generated project related • Project management control supporting measures
• Length of time	• Long-term	• Short-term and long-term

which focuses on supporting the effective and efficient implementation of improvement measures. Carbon management accounting may support all functions and managerial decision-making situations with specialized accounting tools. Sections 3.2 and 3.3 highlight the core issues in carbon management accounting for un-sustainability and for making improvements.

3.2. Carbon accounts of un-sustainability

Carbon accounts, which identify and measure the greenhouse gas emissions, highlight how and in what respect a company is deviating from being sustainable. This step is necessary to increase transparency and to create awareness about the situation and to clarify the sources, drivers and weaknesses that need correction. The carbon information is typically in physical units (i.e. kilogrammes, CO_2-equivalents) but may be related to monetary figures of e.g. costs. Such accounts may be designed to address internal and external accountability. Typical accounting scopes include carbon accounts of production processes, production sites, products, the company as a whole and their supply chains (for examples see e.g. Carbon Trust, 2006; Holliday, 2010). Most information related to un-sustainability may be past-oriented but can be complemented with forecasts of future carbon emission impacts if current operations continue or change, sales expectations are met and business plans are implemented. Such accounts can help corporate leaders develop scenarios and to identify what the main sources and drivers of carbon impacts could be in the future and what internal and external costs and benefits that may result.

Much of the carbon accounting information can be expressed in relative figures (such as kilogrammes of carbon emissions per product sold) whereas the question whether the overall sustainability impact is increasing or decreasing has to be measured in absolute terms (e.g. total carbon emissions of the company for the last year; see e.g. Gray, 2010, or Milne and Grubnic, 2012 who emphasize this aspect). Assessments of the ecological relevance of these emissions are possible in scientific terms expressed with indicators of climate change contribution (e.g. Heijungs et al., 1992), or in monetary terms as external costs caused. Other measures may express the impact relative to industry average, the worst polluter of an industry, all other polluters of a region or the companies' own performance in the past (e.g. Schaltegger and Burritt, 2000).

However, whether a company makes a net contribution to sustainable development or not may not even be fully captured with absolute figures. For example, if a company with substantially lower relative carbon impacts per product (e.g. cars with 90 mg CO_2-emissions per 100 km) than its competitors (which e.g. sell cars with 130 mg CO_2-emissions per 100 km) can increase its market share and grow at the cost of its competitors a crowding-out of the most un-sustainable companies is created (this is e.g. discussed by Schaltegger and Wagner, 2010, as the structural political effect of 'sustainable entrepreneurship'). As the company with the more efficient cars (90 mg CO_2-emissions per 100 km) increases its market share from 20% to 30% and the market share for the companies with 130 mg CO_2-emissions per 100 km decreases from 80% to 70% market share the average as well as the total CO_2-emissions of the whole car fleet in the market will decrease (condition sine qua non). This may even be true in cases of small overall market growth or changing average mileage per car. Although the absolute emissions of the more sustainable (or less un-sustainable) company will increase with its sales and market share growth, it contributes to sustainable development with a structural change of the market through the crowding-out effect it creates. Now, this may be seen as a special case, however, it is a very relevant case if carbon performance is to become a competitive factor and if companies are actually able to contribute to sustainable development through the change of market structures. As a consequence the effect of substituting more un-sustainable products and companies by more sustainable (or less un-sustainable) products and companies has to be measured as a part of carbon accounting. This measure furthermore constitutes one link between carbon accounting for un-sustainability and carbon accounting for sustainability improvements.

Stand-alone carbon reports of un-sustainability are unlikely to develop and serve as a means of transparency as they might just serve pressure groups to blame the company. They can be expected to either be designed to securing legitimacy (e.g. Pellegrino and Lodhia, 2012) or to be evaded as long as they do not contribute to improving corporate performance. Management might not see a use in carbon accounting nor would such accounts from a scientific point of view be useful in *creating* real sustainability improvements. If complemented by accounting for sustainability improvements, however, carbon accounts of un-sustainability – although insufficient – can be an essential part of carbon management accounting by helping to identify the baseline from which improvements start. The effective contribution of carbon accounting will have to be materialized with the design and use of accounting for sustainability contributions.

3.3. Carbon accounting for sustainability improvements

Carbon accounting for sustainability improvements supports the identification, choice, introduction and implementation of carbon reduction action plans and measures. These accounts and accounting processes support management in deciding what measures are most effective in curbing carbon emissions and how carbon improvements can be achieved in the most economical way. Whereas, accounting for un-sustainability mostly highlights conflicts between increasing production and sales with increasing carbon impacts, carbon accounting for sustainability contributions focuses on finding and realizing solutions to reduce un-sustainability. These accounts and procedures are necessary to create improvements at present and for the future. With carbon accounting for sustainability improvements the management creates transparency in the company and possibly also to its external stakeholders about how much the company aims to achieve with what kinds of measures. This approach also supports the assignment of responsibilities and accountability in the company with regard to who is expected to achieve certain improvements, whether the measures taken by the responsible actors are effective and whether the goals are achieved.

Furthermore, *carbon management control* can be developed and used for diagnostic and performance improvement purposes relying on information from carbon accounting for sustainability improvements (e.g. Schaltegger and Burritt, 2010; Lee, 2012). Fig. 5 shows a general management control model (Emmanuel and Otley, 1985) as it has been adopted for environmental management control (e.g. Schaltegger and Sturm, 1998; Henry and Journeault, 2010; Lee, 2012) and can be applied for carbon management control, too. The lines linking inputs, processes and outputs represent real system flows, for example the company internal flow of materials or flows along a supply chain. All other lines represent logical flows of control activity, such as CO_2 outputs or information on the prediction of CO_2 per day in production. Comparing the output measures with the objectives is the basis to afterwards determine causes of deviation and to generate and evaluate alternative corrective actions. The implementation of action furthermore will influence the productive system, which continuous to be managed with the management control cycle.

So far, carbon management control has been barely touched upon in the literature and still offers much scope for research, for

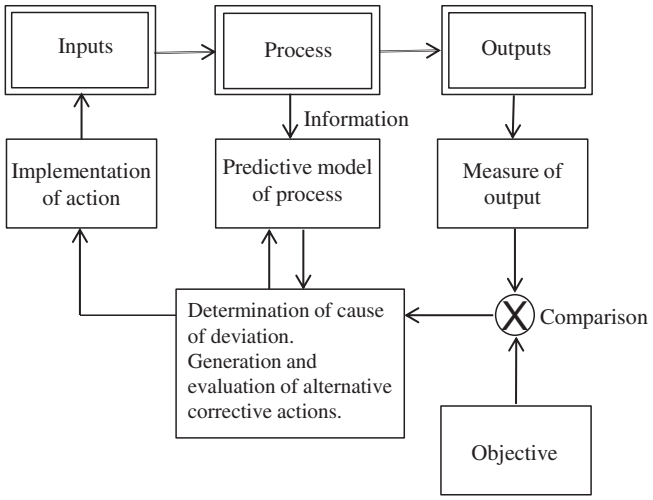


Fig. 5. Carbon management control establishes a system of continuous improvement (source: Emmanuel and Otley, 1985, p. 8) and relies on carbon accounting for making corporate sustainability improvements.

example with regard to different levers of control (Simons, 1995) or the application of performance oriented approaches like the sustainability balanced scorecard (e.g. Figge et al., 2002).

Development of appropriate measures for carbon management is a specific challenge of carbon accounting. Comparisons between current and alternative operations, products, services, etc. as well as between different investment options and development paths help the company to identify and to achieve improvement solutions from environmental, social and economic perspectives. Typical accounting scopes include comparative calculations of alternative production processes, production sites, product designs, product ranges, the company as a whole and supply chains. Most improvement-related information may be present- and future-oriented but can also be compared with past-oriented information on carbon emissions per unit of production or service.

Exemplary *physical carbon accounting* methods for sustainability improvements include ecological investment appraisal to account for the net carbon effect of cleaner production investments, carbon planning and ecological budgets (for examples see e.g. Herzig et al., 2012). The calculation of measures such as the carbon payback period (e.g. the time until the reduction of carbon emissions through the new investment in a photovoltaic installation make up the carbon emissions caused to produce the photovoltaic cells) or the carbon advantage ratio (carbon reductions divided by caused carbon impacts) help to clarify and quantify the efficacy improvements due to carbon reduction activities (see e.g. Schaltegger, 1998). With these accounting procedures, corporate management can aim for carbon reductions of different magnitude and will ideally strive for low-carbon, carbon neutral or even carbon positive processes, products and services. Once introduced into the company, carbon budgets and planning can support the continuous tracking of whether the expected improvements are actually being achieved. Typically, ecological budgeting and planning will work with carbon reduction budgets, which document how much reduction of carbon emissions are planned per period and what carbon budget, i.e. remaining carbon emissions, shall not be exceeded.

Monetary carbon accounting complements these physical accounts and supports carbon management to receive most carbon reduction per invested Euro. With cost and revenue tracking and the calculation of profitability figures, monetary carbon accounting for improvements helps the company to search for more profitable ways of carbon reductions to overcome trade-offs by supporting the identification and development of environmentally, socially and economically beneficial solutions (e.g. Tsai et al., 2012). Furthermore, the management control oriented function of carbon accounting is concerned with tracking whether the plans have been implemented and if the goals have been achieved, in terms of planned carbon reductions, costs and profitability of carbon reduction measures.

3.4. Carbon accounting indicators

The choice of key indicators and the measures to track and express the performance with regard to these indicators is a core task of accounting and management control. To unveil its enabling role, accounting has to link useful carbon indicators with responsibilities and activities in the organization. The basic climate measures of accounting for un-sustainability as well as for sustainability improvements are *CO_2-emissions and CO_2-equivalents*, whereas the latter is more encompassing with regard to the greenhouse effect (e.g. Hoffmann and Busch, 2008; Busch, 2010). On the macro scale these measures are often complemented by assessments and composite indicators like climate change contribution or the carbon footprint (e.g. Wiedmann and Minx, 2007, 2008). On the corporate level the *carbon footprint* has become the main indicator for the carbon intensity of products and supply chains (Pandey et al., 2011). For production processes and sites as well as for the whole company, carbon reduction is mostly measured in relative terms such as CO_2-emissions per product unit or tonnes for the whole company for the last year in comparison with previous years. Additionally, *eco-efficiency indicators* such as CO_2-emissions per Euro of sales can be helpful for tracking and comparison purposes.

Corporate carbon policies, strategies, targets and timetables are essential to help to ensure that the corporate carbon improvement process becomes and continues to be effective in the company implementation process. Carbon policies, climate protection and greenhouse gas policies usually define some general goals and set the foundation for more detailed internal goal setting processes. In this context *benchmarking* can be quantified relative to and compared with the company's historical carbon emissions, specific corporate functions (functional benchmarking), industry average (industry benchmarking), leading competitors (leadership benchmarking) or the goal of carbon neutrality.

Carbon neutrality is often seen as the ultimate goal of sustainability with regard to corporate carbon emissions (e.g. Kilian and Jiménez, 2011; Gösslinga and Schumacherb, 2010). To be effective, reduction of the company's own carbon emissions has to be the first objective. As no company can operate without any environmental impact some carbon emissions will remain in almost any case, even after an effective implementation of the most ambitious carbon emission reduction measures. One way of compensating for these remaining impacts may be achieved through carbon reducing effects of the company's products during the usage phase. For example, a company, which sells energy efficiency improving equipment and services (e.g. insulation for buildings) may be able to reduce more carbon emissions for its customers than it creates through its activities and supply chains. To develop the products and services from this perspective can help companies to make more effective progress in achieving net positive carbon impacts. Properly developed and integrated carbon management accounting tools can be used to help them to track and quantify the carbon reduction benefits of their products and services (e.g. Carbon Trust, 2006).

The costs and benefits related to products and services can be calculated with monetary carbon accounting methods and eco-efficiency indicators by combining physical with monetary

figures. A further possibility to create carbon neutrality is by supporting and financing carbon reduction projects, which are offered by specific climate compensation service companies. In this way, carbon accounting and auditing can support the compensation service provider and the customer company to prevent paper trades without adequately documented reduction effects.

For the global economy, carbon neutrality is an object to strive for but that cannot be achieved through compensations or carbon reduction effects of products and services only. To effectively foster sustainable development corporate carbon accounting has to support population control measures, degrowth of quantitative output and more sustainable consumption creating the needed real net reductions in the total release of carbon dioxide on the global level.

3.5. Corporate actors and areas of application

On the organizational level, carbon accounting can support carbon reduction management and measures for all corporate functions. Carbon management accounting systems are being introduced to gather information in response to the growing regulatory, market and societal requirements, pressures and incentives in an increasing number of countries (see e.g. Stern, 2007; Garnaut, 2008), to design sustainability reports in accordance with the Global Reporting Initiative (GRI) and to make improvements in corporate sustainability ratings pursued for purposes of financial investment analysis (e.g. for the Dow Jones Sustainability Index). Carbon management and accounting may also be driven by the intrinsic motivation of management to make real improvements. All of these reasons may play a role, however, to different degrees for different corporate actors. With the different core tasks of each corporate function, different methods of carbon accounting are relevant and needed (Table 3, Burritt et al., 2011a).

Whereas, *top management* and strategic management may need fairly aggregated information on the total carbon impact of the company and how carbon reduction could support the competitive strategy, the *marketing* people may be interested in carbon labels, certifications and product optimization designs, which can create carbon reduction effects for customers through product innovations, or the *production management* people will need to learn about and implement cleaner production and process efficiency improvements.

The EU Emission Trading System has challenged the *accounting and finance department* and the accounting professions with regard to the value of the assets of emission allowances (e.g. Bebbington and Larrinaga-González, 2008; KPMG, 2011; Schaltegger and Burritt, 2000). In 2011 ACCA (Association of Chartered Certified Accountants) and IFTA (International Emissions Trading Association) organized a roundtable titled, "Hot air or real value, accounting for carbon in the EU ETS" (ACCA, 2011). The title expresses the dilemma accountants face with the evaluation of emission rights and the differences in how they are treated in practice, even among the largest emitters in the EU. Whereas, physical environmental accounting and regulatory-driven

Table 3
Different corporate functions require adapted carbon policies, challenges, methods and have different research implications.

Corporate functions	Carbon policies (examples)	Challenges (examples)	Methods (examples)	Implications for future research (examples)
Strategic and top management	Competitive carbon strategies Corporate policies to achieve Kyoto, national and industry associations' goals	Low carbon intensity as competitive factor; climate neutrality of company; increasing cost of fuels and ETS regulation	Carbon accounting for (un-)sustainability reporting relating to scientific and political goals; accounts of compensation projects; climate (neutrality) audits	Development of carbon competitive strategy; systems to achieve overall carbon impact reduction; linking corporate and international measures
Production management	Process improvement policies	Process and system innovations	Carbon accounts of production processes; comparative carbon accounting for improvements	Software supported carbon accounting linked with core management information systems
Product management	Product policies	Product innovations	Product Carbon Foot print; carbon reduction labels	Systems to secure and to verify total carbon impact reduction
Supply chain management and procurement	Supply chain policies	Climate neutrality of product chains	Carbon impacts supply chain accounting; climate neutrality labels	Systems to create and to secure overall carbon neutrality
Marketing	Carbon reductions, carbon neutrality, low carbon products, etc.	Development of carbon neutral products and company	Linking carbon accounting with pricing and effective marketing communication	Successful launch and positioning of carbon superior products & services
Logistics	CO_2-reduction of transportation, storage and logistics	Technical and software challenges of logistics	Carbon accounts of transportation systems and paths	Development of simple carbon calculators for drivers, software, etc.
Public relations and corporate communications	Media attention NGO attention; carbon information as part of sustainability reporting,	- Identification of NGO and media topics - Collection and integration of carbon information in reports	Stakeholder dialogues Carbon accounting fulfilling GRI and other reporting requirements (e.g. for the 'Carbon Disclosure Leadership Index')	Effective carbon accounting and reporting systems for un-sustainability deducted from stakeholder expectations
Finance	Emissions trading requirements, sustainability ratings, specific carbon reporting requirements of investors and analysts	Integration of carbon information and performance into finance and investor' relations strategy	Investor related carbon finance and accounting methods and certifications (e.g. like the 'Climate Change Reporting Framework' by CDSB, 2010)	Adaptation and development of new finance and accounting methods linking carbon performance with financial performance
HR	Leading innovative low carbon or carbon neutral company	Supporting a carbon reduction motivated workforce	Identification of reduction potentials and formulation of targets for each job; involvement of employees in developing carbon reduction	Internal accounting and reporting supporting awareness, improvement and acknowledgement of achievements

reporting of GHG gases is standardized in Europe and verified CO_2 reports are required, monetary environmental accounting is lagging behind in terms of accounting procedures applied and the audit and verification of reports.

A core challenge for the introduction and establishment of corporate carbon accounting is therefore, to develop systems, which can serve the different needs of all functions in the most efficient manner. Integration of corporate carbon reduction visions, policies, strategies, indicators, timetables and documentation methods for monitoring improvements must be achieved by integrating the company's evolving carbon information management system(s) with its financial accounting procedures.

3.6. Scopes and carbon management accounting tools

From the different foci of top management and corporate functions, it follows that different accounting scopes and methods may be useful and applicable for carbon management accounting. The Greenhouse Gas Protocol distinguishes three scopes which define the accounting boundaries and the areas which carbon management covers to identify and collect information on all discharged and induced greenhouses gases (GHG Protocol, 2004, 2011a,b):

- Scope 1 deals with emissions directly released by the company. This includes production and service processes owned or controlled by the company as well as the corporate fleet of cars and trucks. The GHG protocol covers only the six greenhouse gases listed in the Kyoto protocol. The exclusion of CFCs or NOx from the list reveals the political nature of the GHG accounts as science would dictate the inclusion of all relevant gases into the accounting framework. Companies may report further GHG emission on separate accounts.
- Scope 2 covers indirectly caused emissions for the generation of purchased electricity.
- Scope 3 is optional and extends the accounting scope to emissions indirectly caused through the purchase of all kinds of goods and services such as semi-manufactured goods, transportation services, waste disposal services, outsourced activities, etc. Scope three activities also include the use and waste disposal of products as well as employee business trips, including first class flights of top management.

Fig. 6 shows the carbon management accounting scopes which have been developed and how they relate to the scopes of the GHG Protocol. Whereas, the dominant carbon management accounting activities and methods have an internal company focus (Scope 1), the carbon emissions caused through purchased energy (Scope 2) are often *estimated on basic inventory data* from energy system databases of external data providers and are considered by sustainability managers in specific calculations outside the existing *company's internal management accounting systems.* Sustainable supply chain accounting extends the perspective over the whole supply chain (tier 1, 2, 3, etc.) but does not correspond to Scope 2 (tier 1) nor the Scope 3 definition (covering the whole value chain including supplies, use and disposal or recycling, etc.) of the GHG Protocol. Scope 3 carbon accounting is most challenging as it attempts to consider all direct and indirect carbon emissions of the company as well as its suppliers downstream and the value chain upstream. The GHG Protocol has the ambitious goal that: "Potentially, producers and consumers can be linked within the one reporting framework" (Foran et al., 2005, p. 154).

Conceptually, *supply chain accounting* is designed to measure the carbon impacts for the whole supply chain by documenting and quantifying the impacts of tier 1, tier 2, etc. suppliers (e.g. Kral et al., 2009). In the broader area of sustainability, this approach is required and applied particularly for the audit, assurance, certification and labelling of organic and fair trade food and the fair trade and green labelling of textiles. With regard to carbon issues, companies have started to communicate the carbon footprints of their goods and services (e.g. Beattie and Sale, 2009; Kolk et al., 2008). Although, a more widespread use of product carbon labels has been called for (e.g. Carbon Trust, 2006, 2008) their use continues to be evolving.

For the last five years, different types of carbon labels have been developed (e.g. Upham et al., 2011) which require different carbon accounting approaches and information. Depending on whether the label focuses on carbon intensity, carbon reduction or carbon neutrality, substantially different climate impact related information is needed such as the carbon emissions of the supply chain or the whole product life, or carbon information comparing products before and after reduction measures, or information about the carbon neutrality concept and the relevant calculation bases for each approach. The assessment of product alternatives based on or including primary supply chain data is also used in company decision-making and can be supported with carbon footprint tools (e.g. Lash and Wellington, 2007; Pandey et al., 2011).

For the vast majority of products other than specifically labelled food or textiles, however, the collection of primary data over the whole supply chain has not been done. The building, automotive, electrical appliances, and other industries often have very complex

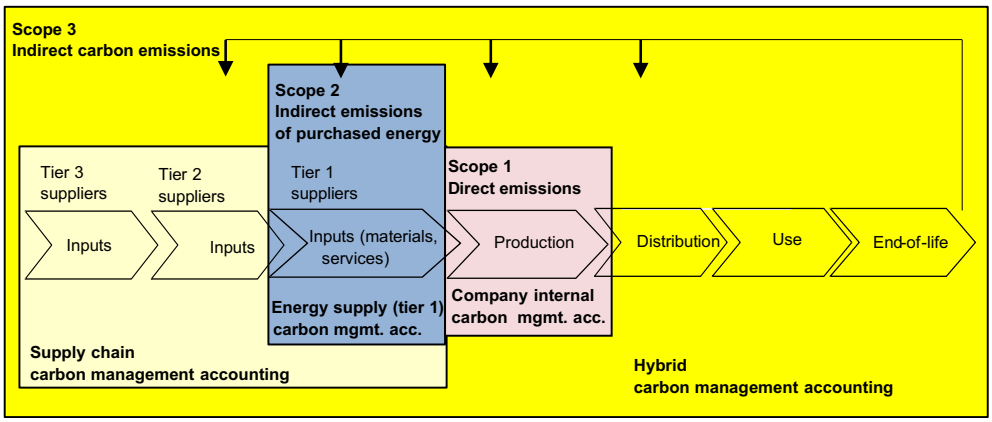


Fig. 6. The different scopes or levels of the 'GHG Protocol' challenge corporate managers to address the different aspects of their carbon impacts with the use of different carbon management accounting tools.

networks of large numbers of suppliers, which makes data collection, particularly from tier 2 and tier 3 suppliers onwards, difficult to manage and expensive to accomplish (McKinnon, 2010). For some industries, confidentiality requirements of suppliers are big challenges. For most of the economy, supply chain accounting may have to use *hybrid accounting* to increase the understanding of the carbon improvement opportunities of suppliers further downstream in the supply chain. Input-output assisted LCAs attempt to capture Scope 3 carbon emissions further downstream in the supply chain (Suh et al., 2004, 2007; Wiedmann et al., 2009) and to broaden the system boundary of life-cycle inventories in LCA or LCC studies (Crawford, 2008; Lenzen, 2002; Lenzen et al., 2003). Hybrid environmental management accounting exceeds a combination of physical and monetary environmental accounting expressed in relative indicators such as discussed in the ISO14031 framework. It combines monetary input–output analysis with physical environmental accounts to develop an estimate of emission flows, which cannot currently be directly measured. In comparison, supply chain carbon accounting and hybrid accounting compete with each other in a trade-off between accuracy and low costs of data availability. Hybrid carbon management accounting is sometimes also used as an auxiliary approach for Scope 1 (Tsai et al., 2012) and for Scope 2 material flow accounting when material flows cannot be measured or only at exorbitantly high costs. Material flows are approximated on the basis of financial information and are assumed to be proportional to monetary flows. Such applications, however, should be treated with caution, as the accuracy of hybrid accounting information is far lower than when using primary data.

Progress is being made within some companies to develop and to test the utility of tools for carbon information management, which can be applied to the different scopes. This has resulted in an increasingly large number of specific carbon accounting methods, which serve different management purposes. A comprehensive *framework*, which provides guidance for a structured overview to classify and identify carbon accounting methods according to *information properties* and *decision situations*, was developed by Burritt et al. (2011b) (based on Burritt et al., 2002). Table 4 provides illustrative examples of carbon management accounting methods for each of these decision-making settings. The framework distinguishes physical and monetary dimensions, the time-frame of decision-making, the length of time-frame (short or long term) and the routineness of the information supplied (regular or ad hoc). It can serve as a guide for management to identify, which tools are most relevant for collecting and managing carbon information for specific situations.

The decision-making context is presented for all three scopes as defined by the GHG Protocol. Most existing approaches, however, focus on Scope 1, whereas, the increasingly popular carbon product footprint and supply chain accounting methods do not match the scope definitions. From the perspectives of information availability, reliability and methodology, the main challenge lies in Scope 3, the accounting for indirectly induced climate change effects. The recognition of the increasing importance of indirect climate impacts through global supply chains, product use and disposal phases is leading researcher to develop new tools to capture indirect supply chain impacts. For example, increasing transportation costs related to GHG emission of aviation can influence retailers as well as manufacturers and competition.

Whereas, carbon accounting procedures and tools to create Scope 1 accounts has many similarities with conventional physical and management accounting, Scope 2 and particularly Scope 3 accounting boundaries require new approaches, which challenge accountants and sustainability managers alike. Typically, carbon accounting and management will be established along the line of these three scopes starting with the direct carbon impacts and

Table 4
The framework of carbon management accounting distinguishes decision-making situations and methods for different corporate contexts (similar to Burritt et al., 2011b, 82).

		Monetary carbon accounting		Physical carbon accounting	
		Short term	Long term	Short term	Long term
Past oriented	Routinely generated Information	1. Carbon cost accounting (e.g. establishing the revenues and costs from carbon emissions certificates sold and purchased weekly on the market)	2. Carbon capital expenditure accounting (e.g. collection of data about annual capital expenditure on carbon reduction technologies)	3. Carbon flow accounting (e.g. collection of daily carbon emission flow information related to production)	4. Carbon capital impact accounting (e.g. calculation of the carbon footprint reduction of a business over the last ten years)
	Ad hoc information	5. Ex post assessment of short term/relevant carbon costing decisions (e.g. assessing the cost savings each month from changing to the use of long life light bulbs in an office block)	6. Ex post assessment of carbon reducing investments (e.g. assessment of life cycle cost savings from investment in production of a new carbon efficient automobile as part of the product mix)	7. Ex post assessment of short term carbon impacts (e.g. collection of information about the reduction in travel miles of an executive as part of a short term carbon reduction programme)	8. Ex post assessment of physical carbon investment appraisal (e.g. review of the carbon reduction achieved by investment in a low carbon logistics network for distributing products)
Future oriented	Routinely generated Information	9. Monetary carbon operational budgeting (e.g. expected monthly monetary savings from carbon reduction related to electricity consumption)	10. Carbon long term financial planning (e.g. forecasting the future financial benefits to be gained from planning to permanently reduce the company's carbon footprint)	11. Physical carbon budgeting (e.g. expected reduction in CO_2 emitted by a commercial building as staff training in green awareness techniques is introduced)	12. Long term physical carbon planning (e.g. expected reduction in emissions of carbon dioxide from projects generated by the research and development department)
	Ad hoc information	13. Relevant carbon costing (e.g. calculating the change in revenues of the next accounting term if CO_2 costs of dirty products are included in the prices charged to customers)	14. Monetary carbon project investment appraisal (e.g. appraisal of expected benefits from investing in a Clean Development Mechanism project to reduce open burning of landfill waste in an overseas country)	15. Carbon impact budgeting (e.g. consideration of CO_2 reduction effect of a project in the next accounting period)	16. Physical environmental investment appraisal (e.g. calculation of total CO_2 reduction effect of clean production investment)

internal information, which can be based upon existing management and production information systems.

Particularly for Scope 3 emissions, new methods of carbon accounting are needed because, in practice, supply chain accounting mainly only quantifies the carbon emissions of tier 1 direct suppliers, or some of the emissions of tier 2 suppliers. Carbon emissions and related costs, however, are caused by all facets of the supply chain, which in case of growing costs for carbon emissions may increase resource and emission prices and have impacts on product profitability. Also, upstream carbon emissions and carbon emission driven changes of cost structures can influence patterns of use and purchasing choices, particularly among business customers.

To extend the environmental management accounting focus beyond scope 1 and scope 2, hybrid carbon accounting techniques are being developed (e.g. Wiedmann et al., 2009). Symmetric input–output tables of industrial sectors (see e.g. Leontief, 1986; Leontief and Ford, 1970; Treloar, 1997) using OECD or Eurostat statistics can be applied to develop a rough estimate of the environmental impacts a company caused by purchasing intermediate products for its production processes (e.g. Wiedmann et al., 2009). This analysis supports a crude benchmarking of the company's performance against the industrial sector average. They do not, however, provide the basis for precise reporting or accountability. The application of hybrid carbon accounting may be justified by high data collection costs or unavailability of data due to confidentiality problems, but should not be an excuse when primary physical carbon data can be collected with reasonable effort. For detailed examinations, further carbon management accounting approaches like life cycle costing can be used.

Lee (2012) illustrated how the three GHG Protocol scopes could be addressed in the automobile industry. Capturing Scope 3 emissions requires the extension of conventional life cycle analysis with methods that can provide an estimate for upstream effects accumulated through the whole supply chain. Assigning upstream effects to the producer also raises questions of shared responsibility among producers and suppliers and for the need to prevent double-counting of carbon effects (Strømman et al., 2009; Lenzen, 2008). Tsai et al. (2012) provided a practical example on how input–output analysis can be combined with activity based costing to more effectively link material flows and flows of costs (for examples see Settanni et al., 2011; Ozawa-Meida et al., 2011). Such applications are anticipated to become increasingly used by companies due to their growing needs to capture costs of indirect material flows.

4. Conclusions and outlook for the future of this evolving field

The reduction of carbon emissions by corporations is both of high relevance for sustainable development, and is an increasingly important business topic. Carbon accounting has played a crucial role on the scientific and political level to inform societal and political institutions and to support decision-makers in designing regulations and international agreements. Günther and Stechemesser (2012) reviewed various understandings and definitions of carbon accounting, which range from general macro-level accounts to corporate accounts. Most of the GHG reduction potential, which has been identified in scientific and political-economic accounts on the macro-level, has to be implemented by organizations. Companies have started to utilise a variety of different carbon accounting methods and practices. As a result, carbon management accounting has developed as the term, which describes the entirety of scopes, methods and procedures of accounting, which deal with greenhouse emissions in the context of corporate activities and influence.

Because most activities are directly or indirectly related to carbon emissions, corporate carbon accounting is not just a topic for the sustainability department. Depending on the industry and internal company development, many corporate functions, including strategic planning, production, procurement, marketing, are involved in different ways in carbon management accounting. In this context, carbon management accounting researchers are challenged to develop differentiated and practical accounting and management control approaches, which can be used to effectively and efficiently support these functions to help companies to reduce their carbon impacts.

In all cases 'accounting for un-sustainability' and 'accounting for sustainability improvements' are possible and are needed as complements to increase transparency and to expand the accuracy and scale of information obtained pertaining to corporate carbon impacts in the three scopes as defined by the GHG protocol. Carbon accounts for un-sustainability are mainly directed towards transparency and have developed as means for helping to ensure corporate legitimacy (e.g. Pellegrino and Lodhia, 2012), and in some cases they serve as a basis for policy development even for non-profit organizations (e.g. Papaspyropoulos et al., 2012). Additional research is needed to support management and stakeholder engagement, the evaluation of alternative measures to reduce carbon emissions and to develop ways to support the effective and efficient implementation of low or zero carbon solutions.

Because the professional financial accounting bodies have not adequately dealt with carbon related financial accounting issues, other organizations have taken the lead in setting accounting and reporting standards. With the Scope 1 and 2, and the introduction of the Scope 3 carbon accounting standard by the Greenhouse Gas Protocol (2011a), the objective for an extended analysis and accounting for supply chains has been introduced. This new carbon accounting area has stimulated the development of hybrid carbon accounting, which combines economic approaches of Leontief Input-Output analysis with environmental management accounting, particularly material flow accounting and activity based costing (see e.g. Lee, 2012; Tsai et al., 2012). Carbon taxes, emissions trading and other regulations influence the costs of inputs as well as the outputs in various ways through higher prices of fossil-based energies in the supply chain and thus, of the purchased products as well as in production and logistics. Furthermore, with the changing costs for customers, carbon intensive products are losing competitiveness, particularly in business-to-business markets. The identification of the accumulated costs and risks related to carbon emissions is therefore, of increasing financial relevance (e.g. Johnston et al., 2008).

Because the dominant energy usage for many products is in the use phase (e.g. by cars, electric appliances, light bulbs) companies are increasingly challenged to provide products and services related carbon information to assist consumer choices. Consumer related accounting methods such as product carbon footprints (e.g. Scipioni et al., 2012), carbon labelling of products and life cycle costing have emerged but require much additional development and dissemination.

The influence of the, thus far mostly theoretically developed corporate carbon accounting approaches, is far from being sufficient. Although various developments were documented to be used in corporate practice and software development, further research is particularly needed to develop specific accounting methods and systems, which support increases in awareness, the identification of reduction potentials, decision-support and the effective implementation of reduction measures.

Burritt and Tingey-Holyoak (2012) and Ascui and Lovell (2012) presented findings on the insufficient dissemination of carbon accounting methods and practice-theory links, and reported how accounting professionals are changing perceptions and competency in this area. This highlights the observation that carbon management accounting is still in an early stage of development and it underscores the urgent need for interdisciplinary collaboration among scientists and practitioners, accountants and engineers to develop methods for practical use. The physical environmental management accounting part of the GHG Protocol is developing quite well (see e.g. GHG, 2011a) but the monetary aspects of carbon accounting are still barely developed. This leaves a blind spot on how changes of physical carbon impacts are related to the economic performance of the company. The exploration of these relationships is to help companies to develop their products and services, core businesses and business models towards carbon neutrality and sustainability, rather than dealing with carbon reduction measures as legal compliance, legitimacy or philanthropic projects in parallel to unchanged *'business as usual'* visions, policies and strategies.

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