Corporate Carbon Performance Indicators
Carbon Intensity, Dependency, Exposure, and Risk

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greenhouse gases (GHGs)
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Summary

The dependency on carbon-based materials and energy sources and the emission of greenhouse gases have been recognized as major problems of the 21st century. Companies are central to the effort to grapple with these issues due to the large material flows they process and their capabilities for technological innovation. It is important, on the one hand, to determine the individual stake companies have in these issues and, on the other, to measure companies’ performance. Since the results of studies thus far have been ambiguous, we define four comprehensive and systematic corporate carbon performance indicators: (1) Carbon intensity is physically oriented and represents a company’s carbon use in relation to a business metric. (2) Carbon dependency illustrates the change in physical carbon performance within a given time period. (3) Carbon exposure reveals the financial implications of using and emitting carbon. (4) Carbon risk estimates the change in financial implications of carbon usage within a given time period. On the basis of these general definitions, we specify the indicators for a standardized application that can support two important stakeholders in their decision making: policy makers, who can include such information when evaluating current climate policies and formulating future ones, and investors and financial institutions, which can compare companies with respect to their carbon performance and corresponding financial effects.
Introduction

The world faces twin energy-related threats: “that of not having adequate and secure supplies of energy at affordable prices and that of environmental harm caused by consuming too much of it” (IEA 2006, 1). With respect to the supply side, the availability of all fossil resources is naturally limited in the long run, and crude oil, as one key carbon input for economies, is thought by many to be about to peak (Bentley 2002; Deffeyes 2003; Campbell 2005). As a result, further price increases for carbon-based inputs are inescapable in the long run (Reynolds 1999; IEA 2006). With respect to the consumption side, global warming will have drastic ecological consequences (IPCC 2007a) and possibly far-reaching economic implications (Stern 2006). Policy makers have started to take up these challenges: For example, the European (EU) has set a greenhouse gas (GHG) reduction target of 20% for 2020 and developed the vision to decarbonize society by 60% to 80% by 2050 (EC 2007b).

Companies are central to paving the way toward a low-carbon society, because a large portion of carbon inputs and GHG emissions stems from industrial production. As a consequence, stakeholders increasingly require companies to disclose their strategies for addressing climate change. In particular, actors in financial markets are investigating the implications of climate change and corporate responses on the competitive position of companies and on risks to shareholder value (e.g., CERES 2006; Innovest 2006). However, business responses to climate and carbon issues have been characterized as ambiguous, and external assessments of corporate efforts have been contradictory, even when the same firms are analyzed (Jones and Levy 2007). Furthermore, for many companies, emissions from their own operations are dwarfed by emissions that occur upstream or downstream in the value chain—for example, those connected to energy provision or product usage, which are often not covered in voluntary GHG emission reports. To increase the reliability of life cycle–wide carbon assessments and to determine performance differences between companies, researchers must have indicators that concisely measure a company’s performance with respect to carbon.

Industrial ecology literature stresses that accounting for carbon-based materials and GHGs has always been an important part of life cycle analysis and modeling (Lifset 2007). For example, Morioka and colleagues (2005) use carbon dioxide (CO₂) emissions as an indicator to design advanced loop-closing systems for the recycling of end-of-life vehicles and electric household appliances. With respect to products and services, the carbon footprint method has become a dominant method (EC 2007a): The Climate Footprint Calculator¹ and analyses of carbon footprints in supply chains (Carbon Trust 2006a) are recent examples. Regarding organizations, the Global Reporting Initiative (GRI 2006) defined broadly applied reporting standards that also include carbon emissions, whereas the World Business Council for Sustainable Development and the World Resources Institute (WBCSD and WRI 2004) developed a sophisticated accounting method for GHGs. Nonetheless, neither the scientific nor the practitioner-oriented literature contains a consistent set of indicators that also includes carbon input materials and that relates the way companies use carbon to their underlying business activities. Rather, different definitions and interpretations of the same expressions abound, and there is no common understanding of how to report or analyze a company’s use of carbon or emission of GHGs.

To help in filling this gap, in this article we aim to increase the transparency of corporate carbon performance assessments by defining four comprehensive and systematic indicators for analysis and reporting purposes. The indicators shed light on the physical and monetary dimensions of a company’s current and future activities with respect to carbon inputs and outputs. We suggest a specification for practical application of these indicators that enables stakeholders to assess a company’s stake in climate change and its efforts toward better managing carbon usage: Policy makers can use such information to formulate and evaluate policies, whereas financial markets can obtain insights regarding the performance of companies with respect to carbon and corresponding financial effects.
A Company’s Link to Carbon

We refer to the extent to which a company’s operations and its value chain are based on carbon as carbon usage. A company’s carbon usage comprises (1) an input dimension that relates to production processes that utilize carbon-based materials and energy and (2) an output dimension that refers to the emission of GHGs from these production processes (Busch and Hoffmann 2007). Although not all GHGs directly relate to carbon, we include them in our considerations in terms of their CO₂ equivalents.

System Boundaries and Scope of Carbon Usage

The carbon usage of a company depends on the industry it operates in, its position in the value chain, and company-specific factors, such as product portfolio or technological equipment. For a comprehensive analysis of a company’s carbon usage, a cradle-to-grave perspective is important (cf. Butner et al. 2008), and direct and indirect carbon inputs and outputs have to be distinguished (see figure 1). For the output dimension, the Greenhouse Gas Protocol Initiative (WBCSD and WRI 2004) developed a classification scheme. This approach is sufficient for analysis of the output dimension of corporate carbon usage. For analysis of monetary implications, however, carbon inputs also matter. Therefore, we extend this scheme and describe different system boundaries as three scopes for direct and indirect levels of carbon usage in the input and output dimensions (see table 1).

Within the gate-to-gate view of scope 1, only direct carbon usage is taken into account, and neither upstream nor downstream aspects are considered. The determination of scope 1 carbon usage requires the least effort in terms of data gathering and analysis. The results display only a very limited part of the actual carbon usage, however, excluding, for example, “gray” carbon usage that occurs during the production of supplied products. In contrast, the combined consideration of scopes 1 and 2 also includes the carbon usage relating to purchased energy. Nonetheless, negative financial effects can still lurk behind other parts of the value chain—for example, when suppliers pass on emission costs to their customers. To address this problem, one can analyze the full value chain, including the upstream carbon usage of the company’s supply chain as well as the downstream carbon usage linked to a company’s products and services (scope 3). Nevertheless, the determination of this scope is shaped by practical limitations, such as data availability and the time required for precise and reliable data analyses.

Measuring Corporate Carbon Performance

Thus far we have centered our remarks on the absolute carbon usage of companies (e.g., the total amount of GHG emissions). This is important for general or aggregated trend

![Figure 1](attachment:carbon_inputs_outputs.png)  
**Figure 1** Carbon inputs and outputs with varying system boundaries.
investigations with a sectorwide or macroeconomic view that can help to identify situations in which individual companies or industry sectors continuously increase their absolute emissions even while governments pursue national emission reduction goals. Nonetheless, to compare the carbon usage across companies and to incorporate changes in a company’s business activities over time (e.g., through mergers and acquisitions), it is important to place the absolute carbon usage in relation to a business metric.

The generation of this type of ratio has been thoroughly discussed in the ecoefficiency literature (e.g., Schaltegger and Sturm 1990; WBCSD 2000). Ecoefficiency measures illustrate the economic output that is obtained from a given resource input or that generates a given environmental effect (DeSimone and Popoff 1997;
Figure 2 Corporate carbon performance indicators.

<table>
<thead>
<tr>
<th></th>
<th>static approach</th>
<th>dynamic approach</th>
</tr>
</thead>
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<tr>
<td>physical units</td>
<td>carbon intensity</td>
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</tr>
<tr>
<td>monetary units</td>
<td>carbon exposure</td>
<td>carbon risk</td>
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</table>

Determining Carbon Intensity

The term carbon intensity has been used in various ways in the literature as well as in practical applications. On the macro level, approaches have considered carbon inputs (EIA 1995; Bosetti et al. 2006; Huesemann 2006) as well as carbon outputs (Lebel et al. 2007; Raupach et al. 2007) to determine intensity indicators that describe carbon flows within an economic system. On the micro level, carbon intensities are used for the internal or external analysis of companies, for reporting purposes, and for ranking different companies (for examples, see table 3). The current usage of these indicators is problematic for four reasons, however: Different synonyms abound for the same underlying indicator, the same synonyms are used for different underlying indicators, system boundaries vary among scopes 1–3, and carbon intensities are only based on carbon outputs, not on carbon inputs. This makes it very difficult for external stakeholders to compare the carbon intensities of different companies.

To derive a consistent terminology, we suggest a general definition of the term carbon intensity.

**Definition 1:** Carbon intensity relates to a company's physical carbon performance and describes the extent to which its business activities are based on carbon usage for a defined scope and fiscal year. The intensity is measured by the ratio of a company's carbon usage in absolute terms to a related business metric. The carbon usage specifies the amount of carbon the company utilizes or emits for a chosen scope and fiscal year. The business metric is a measurement of a company's financial performance for the same fiscal year. In the determination of a company's carbon intensity, the time frame and the material flow level are relevant.
### Table 3 Differences in use of the term carbon intensity

<table>
<thead>
<tr>
<th>Objective</th>
<th>Indicator</th>
<th>Carbon usage</th>
<th>Business metric</th>
<th>Source</th>
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<tbody>
<tr>
<td>Tracking and reporting on emission reductions</td>
<td>Metrics for measuring GHG emissions</td>
<td>CO$_2$-eq (in tons; scope varies)</td>
<td>Unit of product (no specification)</td>
<td>Hoffman (2006)</td>
</tr>
<tr>
<td>Comparison of different kinds of fossil fuels</td>
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<td>Fuel unit (volume or mass) or British Thermal Units</td>
<td>EIA (2007)</td>
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<tr>
<td>Ranking of investment funds</td>
<td>Carbon intensity</td>
<td>CO$_2$-eq (in tons; scope 1–3)</td>
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<td>Trucost (2006)</td>
</tr>
<tr>
<td>External analysis of companies</td>
<td>GHG emission intensity</td>
<td>CO$_2$-eq (in tons, scope 1–3)</td>
<td>Unit of production (no specification)</td>
<td>Maxime and colleagues (2006)</td>
</tr>
<tr>
<td></td>
<td>Carbon intensity</td>
<td>CO$_2$ (in kg; scope 1)</td>
<td>Unit of production (in MWh)</td>
<td>Voisin and Lamotte (2006)</td>
</tr>
<tr>
<td></td>
<td>Carbon intensity</td>
<td>CO$_2$ (in g, scope 1)</td>
<td>Unit of production (in kWh)</td>
<td>Hutchinson (2006)</td>
</tr>
<tr>
<td></td>
<td>Carbon intensity</td>
<td>CO$_2$-eq (in tons; scope 1–3)</td>
<td>Turnover, EBITDA, or market capitalization (in £)</td>
<td>Henderson and Trucost (2005); Societe Generale (2007)</td>
</tr>
<tr>
<td>Internal analysis and reporting</td>
<td>GHG intensity</td>
<td>CO$_2$-eq (in tons; scope 1)</td>
<td>Unit of production (thousand barrels of oil equivalent)</td>
<td>BP (2006)</td>
</tr>
<tr>
<td></td>
<td>GHG emissions intensity</td>
<td>CO$_2$-eq (in tons; scope 1–2)</td>
<td>Unit of production (cubic meters of oil equivalent)</td>
<td>Encana (2007)</td>
</tr>
<tr>
<td></td>
<td>Production carbon intensity</td>
<td>CO$_2$-eq (in tons; scope 1–2)</td>
<td>Unit of production (cubic meters of oil equivalent)</td>
<td>Petro-Canada (2007)</td>
</tr>
<tr>
<td></td>
<td>CO$_2$-eq emission intensity</td>
<td>CO$_2$-eq (in kg; scope 1, partly scope 2–3)</td>
<td>Sales (in US$)</td>
<td>Brambles (2006)</td>
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<td></td>
<td>Key figure for GHG emissions</td>
<td>CO$_2$-eq (in tons; scope 1–3)</td>
<td>Sales (in CHF)</td>
<td>Roche (2007)</td>
</tr>
<tr>
<td></td>
<td>Emissions volume per sales unit</td>
<td>CO$_2$-eq (in tons; scope 1)</td>
<td>Sales (in 100 Yen)</td>
<td>Toyota (2006)</td>
</tr>
<tr>
<td></td>
<td>Specific emission data</td>
<td>CO$_2$ (in kg; scope 1)</td>
<td>Unit of production (cementitious materials in tons)</td>
<td>Holcim (2005)</td>
</tr>
<tr>
<td></td>
<td>Environmental performance indicator</td>
<td>CO$_2$ (in kg; scope 1)</td>
<td>Unit of production (in tons)</td>
<td>Nestlé (2007)</td>
</tr>
<tr>
<td></td>
<td>Carbon intensity</td>
<td>CO$_2$ (in tons; scope 1)</td>
<td>Unit of production (in MWh)</td>
<td>E.on UK (2006)</td>
</tr>
</tbody>
</table>

*Note: GHG = greenhouse gas; CO$_2$-eq = carbon dioxide equivalent; CO$_2$ = carbon dioxide; EBITDA = earnings before interest, taxes, depreciation, and amortization; CHF = Swiss Francs.*
With respect to the time frame, the status quo \( (t_0) \) and the predicted \( (t_1) \) carbon intensity can be distinguished. The status quo carbon intensity is based on verified data (e.g., of the previous fiscal year) and as such provides a realistic picture of the company’s current carbon intensity. It conforms to the established use of this indicator, as exhibited in table 3. The predicted carbon intensity relates to a future time \( t_1 \) and is commonly not reported. It requires specification of three parameters: First, a time period has to be defined over which the analysis of the company’s carbon performance will be conducted. Second, future price and market conditions have to be estimated on the basis of forecasts such as those issued by the International Energy Agency (IEA). These should specify carbon-related conditions of the business environment and incorporate all relevant information known or assumed to influence the carbon and energy market (notably, future carbon prices; cf. table 4). Third, the company-specific carbon usage in the future has to be estimated. Reflecting the assumptions regarding the future price and market conditions, technological options and alternative production processes have to be identified that a company is likely to use to realize carbon optimization potentials. These potentials relate to efficiency increases (e.g., energy efficiency) and substitution options (e.g., using renewable energy sources instead of fossil fuels). The extent to which a company is able to take advantage of these potentials is determined by the individual status of a company’s technology equipment, current government policies, and other factors.

Given the material flow level, a company’s carbon input or carbon output intensity can be distinguished, depending on the way carbon usage is calculated. The carbon input intensity relates to the amount of carbon that is needed within the production process. For example, in the plastics industry, the carbon flows can be included that are required for the production of polymers and do not produce emissions. In contrast, the carbon output intensity accounts for the emission of GHGs and acknowledges the company’s internal and external efforts to curb emissions via measures such as carbon offsetting (WBCSD and WRI 2004).

The amount of carbon inputs \( C_I \) in tons of carbon is calculated as

\[
C_{I, t} = \sum_{k=1}^{K_I} C_{I,k,t}
\]

where \( k = 1, \ldots, K_I \) is the index for the \( K_I \) different inputs and \( t \) is the fiscal year of analysis. The scope 1 input data can be obtained from an input-output analysis or derived from the company’s accountancy or controlling systems. The determination of scope 2 carbon inputs requires the amount of purchased energy and information regarding the specific energy mix—that is, the carbon inputs for producing the purchased energy—which is available in standard databases, such as the ecoinvent database. For a complete allocation of scope 3 carbon inputs, a life cycle assessment is usually necessary (e.g., Ardenti and Gilardi 2007; Wedema et al. 2008). The carbon input intensity \( (C_{I\text{In}}, t) \) can be derived for a chosen scope \( i = 1, 2, 3 \) and fiscal year \( t \) when a business metric (BM) is taken into account.

\[
C_{I\text{In}, t} = \frac{\sum_{k=1}^{K_I} C_{I,k,t}}{BM}
\]  

The carbon output intensity is based on a company’s GHG emissions, measured in CO₂ equivalents and denoted by \( k = 1, \ldots, K_O \). Scope 1–3 emissions can be obtained from the same sources as described for carbon inputs. In addition, carbon-relevant activities, such as GHG reductions via offsetting, have to be taken into account. The carbon output intensity \( (C_{O\text{In}}, t) \) can be derived analogously to equation (1a).

\[
C_{O\text{In}, t} = \frac{\sum_{k=1}^{K_O} C_{O,k,t}}{BM}
\]

**Determining Carbon Dependency**

In the literature, the notion of carbon dependency has been treated on a macroeconomic level (e.g., Liberatore 2001). It is related to the energy dependency of nations, which refers to the dependency on external energy resources, such as the EU’s dependency on Russian natural gas (Kuik 2003). Carbon dependency can be interpreted in the sense of such an energy dependency but also as one country’s dependency on another for meeting emission reduction targets through
the importation of low-carbon fuels or emissions trading (Wieczorek 2003). In this way, carbon dependency is a “carbon (trading) dependency” (Kuik 2003, 236). We transfer this idea to the micro level and extend it by introducing a time component.

**Definition 2:** Carbon dependency describes the change in a company’s physical carbon performance within a given time period. The indicator is measured as the company’s relative performance change from the status quo to the predicted carbon intensity.

A company’s carbon dependency indicates what percentage of the current status quo (t₀) carbon intensity will remain, with the presumption that the company pursues its business under the assumptions made for estimating its predicted carbon intensity (t₁) in the three steps (above). If a company undertakes all economically feasible efforts to reduce its carbon intensity under these assumptions, the carbon dependency describes the degree to which the company is able to reduce its carbon intensity. As a result, a highly carbon dependent company is hardly able to reduce its carbon intensity over the considered time period. Given the same scope (i = 1, 2, 3 for both carbon intensities (t₀ and t₁)), the carbon dependency (Cdₑ) is expressed as a percentage of the t₀ carbon intensity for the time period Δt = t₁ − t₀.

\[
Cdₑ_{i,Δt} = \frac{C_1ln_{t_i,t_0}}{C_1ln_{t_0,t_0}} \times 100 \quad \text{or} \quad Cdₑ_{O,Δt} = \frac{C_0ln_{t_i,t_0}}{C_0ln_{t_0,t_0}} \times 100 \quad (2)
\]

**Determining Carbon Exposure**

The term carbon exposure is often used in practitioner-oriented reports. Carbon Trust (2006b), Henderson and Trucost (2005), and Societe Generale (2007) deliver ratio-based definitions that relate current carbon outputs to different hypothetical future cost figures. As a result, their metrics mix two time frames when carbon usage of t₀ is related to carbon prices of t₁. Furthermore, these authors utilize different business metrics and scopes for carbon usage. Taking a broader view, Schultz and Williamson (2005) also recommend including diverse cost effects relating to customer and shareholder sentiments and climate change events (e.g., rising sea levels) in assessments of a company’s carbon exposure.

In sum, there is neither a clear distinction between different time periods nor a common understanding of the underlying parameters for assessing companies’ carbon exposure. Therefore, we suggest a combined consideration of the input and the output dimensions of a company’s carbon usage in one monetary term for one point in time.

**Definition 3:** Carbon exposure relates to a company’s monetary carbon performance and describes the monetary implications of the business activities due to carbon usage for a defined scope and fiscal year.

The exposure is measured by the ratio between a company’s carbon usage in monetary terms and a related business metric. Through the use of prices, the two ratios that were necessary on the material flow level (i.e., carbon input and output intensity) can be combined in one monetary figure (carbon exposure). One calculates the carbon usage in monetary terms by applying the input prices \( p_{Ik} \) with \( k = 1, \ldots, K_I \) for each unit \( C_{Ik} \) and the output prices \( p_{Ok} \) with \( k = 1, \ldots, K_O \) for each unit \( C_{Ok} \). Carbon input prices are determined by the mass fraction of each carbon-containing input (e.g., the extent to which products are composed of specific carbon inputs) and the expenditures associated with the initial carbon source (e.g., costs for crude oil and related carbon taxes). On the basis of equation (1), a company’s carbon exposure (\( CEx \)) can be derived for a fiscal year \( t \).

\[
CEx_{i,t} = \frac{\sum_{k=1}^{K_I} C_{I_k,t} \times p_{I_k,t} + \sum_{k=1}^{K_O} C_{O_k,t} \times p_{O_k,t}}{BM} \quad (3)
\]

Similar to carbon intensity, the status quo (t₀) and the predicted (t₁) carbon exposure can be distinguished. For a company’s status quo (t₀) carbon exposure, we differentiate between two cost approaches, one representing a company-internal perspective and the other a market perspective. The company-internal perspective considers actual costs of fossil fuels and purchased energy during one fiscal year (t₀) as obtained from the company’s cost accounting system. To determine the cost of the fossil fuel-related purchased energy, one has to incorporate the country-specific energy mix into the calculations (the percentage of
Table 4 Cost approaches for determining future carbon prices

<table>
<thead>
<tr>
<th>Approach</th>
<th>Costs to be determined for</th>
<th>Source (e.g.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Efficiency increase and fossil fuel substitution</td>
<td>Industry specifications: Metz and colleagues (2001), Llewellyn (2007), or Vattenfall (2007)</td>
</tr>
<tr>
<td></td>
<td>Offsetting</td>
<td>Average prices per ton via CDM project: Capoor and Ambrosi (2007)</td>
</tr>
<tr>
<td>Abatement costs based on mitigation options</td>
<td>Depletion of fossil fuels</td>
<td>External costs of oil consumption: Sabour (2005)</td>
</tr>
<tr>
<td></td>
<td>Damage related to carbon emissions</td>
<td>Losses due to the depletion of resources such as oil: Weitzman (1999)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Social cost of carbon emissions: Clarkson and Deyes (2002)</td>
</tr>
</tbody>
</table>

Note: GHG = greenhouse gas; CDM = clean development mechanism.

carbon-based energy production). Similarly, carbon output costs due to, for example, the European Emission Trading Scheme (EU ETS) or voluntary emission reductions (e.g., offsetting via clean development mechanism [CDM] projects) have to be accounted for. In contrast to this company-internal perspective, the use of carbon cost based on market prices follows an opportunity cost logic, and company-specific price conditions are not taken into account. The advantage of utilizing carbon costs based on market prices is that for comparative analyses of different companies, only one price for each input and output has to be determined, which can be obtained from public sources. This reduces complexity and facilitates the monetary assessments involved when more than one company is analyzed.

To estimate the company’s predicted \( (t_{1}) \) carbon exposure, one has to take into account the same carbon-related conditions of the business environment as applied for the \( t_{1} \) carbon intensity. For the future carbon prices \( (p_{k,t1} \) and \( p_{k,t,t1} \)) for the carbon inputs \( (C_{i,t1}) \) and outputs \( (C_{O,t1}) \), we distinguish among three approaches (see table 4).

First, scenarios for future prices can be applied, which have to take into account regulatory and market risk and can be based on one’s own analyses or on forecasts in the literature. Notably, the scenarios must account for typical correlations between market prices of fossil fuels and CO\(_2\) allowances (Bailey 1998; Montero and Ellerman 1998; Voisin and Lamotte 2006). An estimation of future costs of carbon (CO\(_2\) equivalents) has to be included, for example, when an emission-trading scheme is likely to be in place. One can do this either by choosing an opportunity cost perspective or by assuming a fixed percentage of grandfathered allowances. In the former case, the same price is applied for all GHG emissions; in the latter case, a price would be considered only for a certain percentage of all emissions. Allowance prices have fluctuated considerably in the past and are likely to remain volatile in the future. Forecasts for future GHG price levels are generally difficult, as prices will depend on not yet fully specified variables, such as evolving climate policy (Trexler 2005). One the one hand, forecasts can be derived from historic market prices or forwards for EU ETS allowances, but they should further include a scenario component. One can obtain this component by following a dynamic approach—for instance, taking into account decision points in the international policy process.
and historic price volatilities. Alternatively, to reduce complexity, one could choose a linear approximation assuming a steady price increase (e.g., due to inflation). On the other hand, GHG price forecasts can take into account policy scenarios, resulting effects on carbon markets, and further variables, such as market psychology. Notably, this approach is relevant for companies when they are incorporating future GHG prices in strategic management by determining a “best available corporate forecast” (Trexler 2005, 12).

Second, sector-specific abatement costs can be applied that are associated with corporate measures to curb carbon usage. Basically, three options exist to reduce a company’s carbon usage: efficiency increases in existing production processes, substitution away from fossil fuels to become independent of carbon resources, and offsetting strategies to compensate emissions (Weinhofer and Hoffmann, forthcoming). When one is applying abatement costs to determine future carbon costs, it is important to acknowledge that corresponding measures not only generate costs (e.g., by requiring investments) but also reduce costs (e.g., by increasing efficiency) or even might generate additional revenues (e.g., by an excess of allowances). Therefore, the dynamics between additional incurred costs and resulting cost savings and revenues have to be taken into account.

Third, external costs can be included in a long-term business perspective (Scholz and Wiek 2005). Costs of external effects are usually calculated on the macroeconomic level (e.g., Peskin and Angeles 2001); their application on the company level follows the “polluter pays” principle. With respect to carbon inputs, there are efforts in the economic literature to attach a price to the depletion of fossil fuels (e.g., Weitzman 1999). With respect to carbon outputs, cost due to external effects of emitting GHGs can be determined by the cost–benefit or the marginal cost approach (Clarkson and Deyes 2002). Both approaches utilize a figure for the damage per ton of carbon emitted.

**Determining Carbon Risk**

In general, the term carbon risk is often used to describe any corporate risk related to climate change or the use of fossil fuels. Most of the practitioner-oriented reports cited thus far do not explicitly distinguish among carbon exposure, carbon risk exposure, and carbon risks. As a clear definition, Urdal and colleagues (2006) use the term value at risk from carbon and calculate the effects of different price scenarios for CO2 on the equity value of an energy utility. Also, Carbon Trust (2006b) measures the risk from climate change in terms of a carbon exposure (a price for emissions is applied) and further regulatory and market dynamics as well as broader climate change impacts. The resulting risk value is expressed as a percentage of the earnings before interest and taxes (EBIT). We build on this understanding of carbon risk as a foresight indicator but emphasize that carbon risk describes the likely change in carbon-related monetary implications for a company, which one can obtain by determining a company’s carbon exposure for both time periods separately and comparing the change between $t_1$ and $t_0$.

**Definition 4:** Carbon risk describes the change in a company’s monetary carbon performance within a given time period. The indicator is measured as the relative performance change from the status quo to the predicted carbon exposure.

A company’s carbon risk indicates by what percentage current status quo ($t_0$) carbon exposure will change if the company pursues its business under the assumptions for the predicted carbon intensity ($t_1$). On the basis of the carbon price scenarios designed for determining the predicted carbon exposure ($t_1$), the carbon risk displays how the relative monetary relevance of carbon is likely to decrease or increase for the company. As such, it facilitates the comparison of the monetary implications of different companies’ carbon usage over time. As a result, a company with a high carbon risk will face a significant increase in the relevance of its carbon performance for the company’s costs and profits over the considered time period. If we assume the same scope $i = 1, 2, 3$ for both carbon exposures ($t_0$ and $t_1$), the resulting carbon risk ($CR_i$) is derived for the time period $\Delta t = t_1 - t_0$.

\[
CR_{i, \Delta t} = \left( \frac{CE_{X_i,t_1}}{CE_{X_i,t_0}} - 1 \right) \times 100 \tag{4}
\]


Specification of the Performance Indicators

The four indicators describe different areas that are important in the analysis of a company’s carbon performance. The choice of scope of analysis, business metrics, and cost approach determines the explanatory power of the results. Due to the multitude of options pursued in the literature, there is currently a lack of transparency regarding the applied methods. Comparative analyses are impeded, as companies as well as analysts use different approaches arbitrarily. Therefore, we specify our general definitions and suggest one specific set of indicators that appears most promising as a standardized approach to the practical application of the external analysis of companies (table 5). Data availability can be limited, however—for example, regarding scope 3 carbon usage or company-specific costs. Therefore, our approach represents a trade-off between the public availability of data and the requirements for a standardized application of comprehensive indicators.

To determine the carbon intensity, we suggest the consideration of carbon outputs, as this indicator points to corporate efforts in terms of offsetting as well as internal measures, such as efficiency increases. Furthermore, we suggest a focus on scope 1–2, as the determination of scope 3 remains complex (Carbon Trust 2007). The carbon exposure indicator in $t_0$ relies on market prices, because this significantly reduces data-collating efforts in analysis of different companies. For deriving the carbon output cost for $t_0$ carbon exposure we suggest to consider the actual costs for emission reduction certificates related to scope 1 GHG emissions. For all other emissions we suggest taking an opportunity cost perspective. This entails considering a price in $t_0$ for all scope 2 GHG emissions if an emission trading is in place and a price in $t_1$ for all scope 1–2 GHG emissions; potential effects of grandfathering and other effects, such as the actual amount of required allowances in $t_1$, are neglected. Furthermore, we suggest taking the average price of EU ETS allowances of $t_0$ and applying an annual inflation rate to approximate for the future carbon price.

An Example

To illustrate the practical application of the suggested indicators, we analyze two hypothetical companies that face identical starting points. Both are industrial companies based in the United States that generate their own GHG emissions (scope 1) and require externally produced energy (scope 2). As both companies produce a variety of products, we chose sales as business metrics and assume an annual growth in production and sales of 5%. We assess...

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Note: IEA = International Energy Agency; EIA = Energy Information Agency; GHG = greenhouse gas; EU ETS = European Union Emission Trading Scheme.
the carbon performance within the time frame 2006–2015 for both companies. The price per ton of carbon for scope 1–2 carbon input has been calculated to be US$200 in 2006 and is assumed to increase to US$300 in 2015. In 2006, neither company was subject to emission trading requirements, nor did either consider offsetting options; therefore, no carbon output prices have to be considered. The average EU ETS allowance price in 2006 was about US$25.47, which is applied for all scope 1–2 GHGs in 2015, taking into account an inflation rate of 2%.

Due to increasing stakeholder pressure, both companies undertake measures to optimize their carbon performance. Company A identifies areas for internal process improvements, which serves to hold fossil fuel consumption constant while production increases. Nevertheless, the company’s efficiency for purchased energy does not improve and, thus, its energy consumption grows proportionately to the production increase. Company B takes advantage of governmental financial support programs and substitutes half of its fossil fuel consumption with renewable energy sources. Furthermore, the company increases

![Figure 3](image-url) Carbon performance assessment of two companies. t = tons; Mio $ = million U.S. dollars.
operational energy efficiency and cuts down on scope 2 carbon inputs, although this is counter-balanced by a production-related increase in energy consumption.

Figure 3 shows the assessment results. For 2006, both companies have the same carbon output intensity of 1,243 tons of carbon per million U.S. dollars in sales. Due to its efforts, company A reduces its intensity, which results in a carbon dependency of 79%. Company B reduces its carbon intensity more strongly, bringing it down to 53%. This has implications for the monetary carbon performance: For 2006, both companies have a carbon exposure of 6.78 cents per dollar sales. Company B almost remains at this level and, thus, faces a moderate carbon risk of 10%. By contrast, company A has to cope with a significant increase in the financial relevance of carbon, expressed by a carbon risk of 62%. The increase in carbon costs results in an increase of its carbon risk, although the company reduces its carbon intensity. For policy makers, the assessment results indicate that the financial support program can be effective: Company B’s carbon dependency is one third lower than company A’s. For financial stakeholders, the assessment results illustrate that an investment in company B is less risky from a carbon perspective than investment in company A: Company B’s likely increase of the financial relevance of carbon is six times lower.

Discussion and Conclusion

In this article, we discuss existing approaches for assessing the carbon performance of companies and conclude that there is no common agreement on how to conduct corresponding assessments. We suggest a holistic perspective on carbon flows on the micro level and define a systematic and comprehensive approach based on four corporate carbon performance indicators. We differentiate between the physical and monetary spheres and between current and future performance. The suggested specification of the indicators facilitates their practical use and aims at a standardized approach for analysis and reporting purposes.

We see two main stakeholders as users of the suggested indicators. For policy makers, the two physical indicators illustrate the carbon hot spots in a value chain that could be targeted for carbon reduction policies. The two monetary indicators reveal which carbon costs and risks lurk behind the business activities of companies and how companies’ policies might affect their future competitiveness. As such, policy makers can utilize the indicators when formulating climate policies and as tools to evaluate whether existing policies have been effective. For financial markets, the physical indicators provide insights regarding a company’s carbon management efforts and its optimization potentials. The monetary indicators show carbon’s present and future financial implications for companies. Accordingly, information can be used to optimize investment portfolios or determine risk premiums. As such, actors in financial markets will be able to readjust their investment analyses and loan assessments and therefore help pave the way toward a low-carbon future. In addition to these two external stakeholders, companies can obtain insights regarding the carbon-related enhancements or risks of their production processes and facilities. On the basis of such information, they can assess future investments and projects or analyze existing processes. Moreover, they can utilize the corresponding information within marketing or corporate reporting.

Our suggestion for a standardized approach encompasses corporate scope 1–2 carbon usage. This raises the question of whether a life cycle–wide consideration would be more appropriate. Life cycle assessments (LCAs) can deliver precise results for the life cycle–wide carbon analysis of products and services. If this is the purpose of an analysis, an LCA should be conducted. For the purpose of analyzing organizations (our aim in this article), the GHG protocol (WBCSD and WRI 2004) seems to be more appropriate. Because the applicability of scope 3 is rather complex, however, we suggest a specification based on a scope 1–2 approach. Nevertheless, future research should focus on facilitating a scope 1–3 approach. Most importantly, this requires clear industry-specific conventions on which carbon usage should be considered in scope 3, given the feasibility of data collection. Specialized service providers, such as Centre Info SA or Trucost Plc, can provide initial data sets as a basis for this research. Furthermore, organizations such as...
the Global Reporting Initiative\textsuperscript{11} or the Carbon Disclosure Project\textsuperscript{12} could extend their reporting frameworks to help gather these data. This also applies to other discussed data, such as carbon input costs or expenses relating to emissions trading. Such considerations could then further include the costs of internalizing external effects and could describe for stakeholders the overall negative carbon externalities caused by individual value chains.

**Notes**

1. See http://bie.berkeley.edu/files/ConsumerFootprintCalc.swf.
2. In the Kyoto Protocol, six greenhouse gases are specified, which are measured according to their global warming potential in CO\textsubscript{2} equivalents: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. To consider all six under the umbrella of carbon is consistent with the other approaches (e.g., the carbon footprint; Carbon Trust 2007). Furthermore, CO\textsubscript{2} accounts for the main proportion, as, on average, about 93% of GHG emissions of companies in the FTSE 100 (i.e., a share index of the 100 most highly capitalized companies listed on the London Stock Exchange) are CO\textsubscript{2}-related (Henderson and Trucost 2005). For a description of the methods for calculating CO\textsubscript{2} equivalents, see IPCC 2007b.
3. Editor’s note: For extensive analyses of eco-efficiency, see the special issue of this journal on eco-efficiency and industrial ecology, volume 9, number 4 (www3.interscience.wiley.com/journal/120129080/issue).
4. See www.ecoinvent.org; a list with further database providers can be found at http://lca.jrc.ec.europa.eu/lcainfohub/databaseList.vm.
5. See, for example, www.pointcarbon.com or www.wtrg.com.
6. To determine these costs, one has to consider separately the amount of each carbon input (for scope 1 and 2) and the related prices in \( t_0 \) and \( t_1 \). For example, carbon input prices in 2006 were $719.30/t carbon for distillate fuel oil, $474.52/t carbon for natural gas, and $85.96/t carbon for other industrial coal (on the basis of our own calculations and EIA [2008, table A3]). Within this example, we assumed scope 1 and 2 to have the same average carbon costs in \( t_0 \) ($200/t) and \( t_1 \) ($300/t).
7. The average price was about EUR18.1 per ton, and we applied an exchange rate of US$1.4/EUR. For simplicity, we disregarded the high volatility of this price in 2006.
8. This was one main outcome of the recent expert workshop 34th LCA Discussion Forum: Life Cycle Assessment Versus CO\textsubscript{2} Footprint? held on 14 March 2008, Lausanne, Switzerland (www.lcainfo.ch/DF/DF34/Program.htm).
12. See www.cdproject.net.

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